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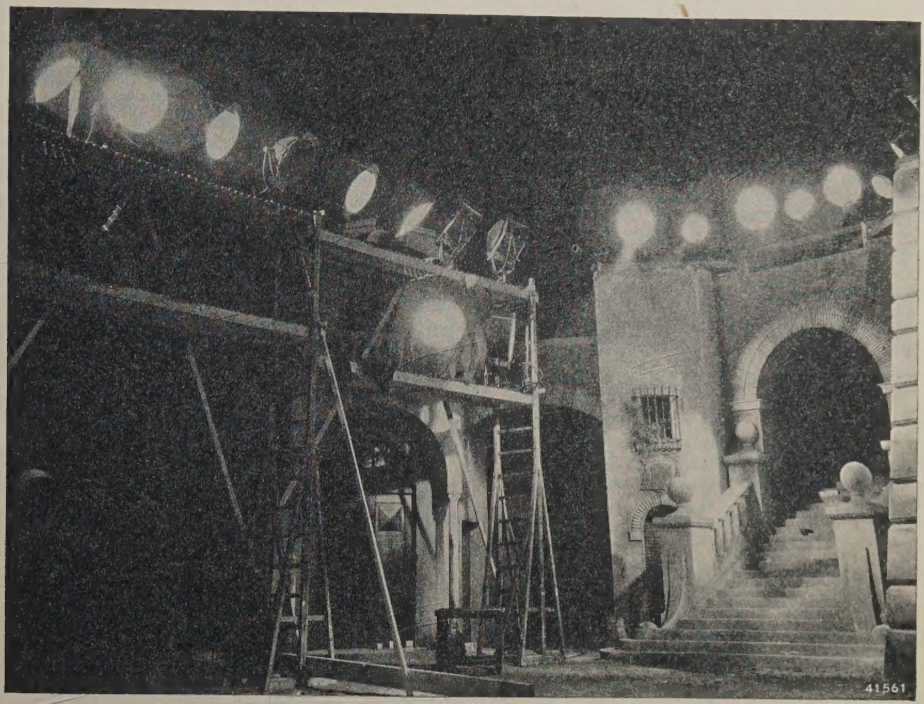

LIGHT SOURCES FOR CINEMATOGRAPHY

by Th. J. J. A. MANDERS. 621.32 : 778.53

For making cinematographic exposures lamps are needed which have high light intensity and good actinic effect. These requirements led originally to the use of arc lamps, while at present incandescent filament lamps are often used. The latter are more satisfactory, especially for making sound films, since, in contrast with arc lamps, they burn absolutely noiselessly. In this article the construction of incandescent lamps for film making is discussed. These lamps are characterized by a heavily loaded incandescent body with relatively small dimensions of the bulb. The fixtures used in the film studio (banks and batteries of lights and spotlights) are also briefly discussed, while in conclusion several special constructions are dealt with which are used when extremely heavy requirements are made.

When the first cinematographic pictures were made by Edison in 1889 he had already had ten years' experience in making incandescent lamps. At first sight, therefore, it seems strange that Edison made no attempt to use incandenecent lamps for illuminating the set, but worked exclusively by daylight. A closer consideration of the properties of the carbon filament lamps and the photographic emulsions of those times, however, shows that the electric lamp as an aid in photography was out of the question at that time. In order to obtain a good photographic effect it is necessary that a sufficiently large part of the radiation of the light source be emitted in those wavelengths for which the film emulsion is chiefly sensitive. Now in those days the emulsions were only sensitive to light of short wavelengths, while the carbon filament lamp emits light mainly of long wavelengths. The actinic effect of the light was thus extremely small; in fact it was so small that it was practically impossible to use it for photography.

In order to form a quantitative idea we shall assume that the emulsion possesses the same sensitivity for all wavelengths below a certain

limiting wavelength λ_0 and is totally insensitive above this wavelength. Furthermore we shall consider the radiation of the incandescent lamp as that of a black body of a given temperature T. The percentage of radiation energy which is actinically effective then depends exclusively upon the product of λ_0 and T ; this calculated dependence is reproduced in *fig. 1.*

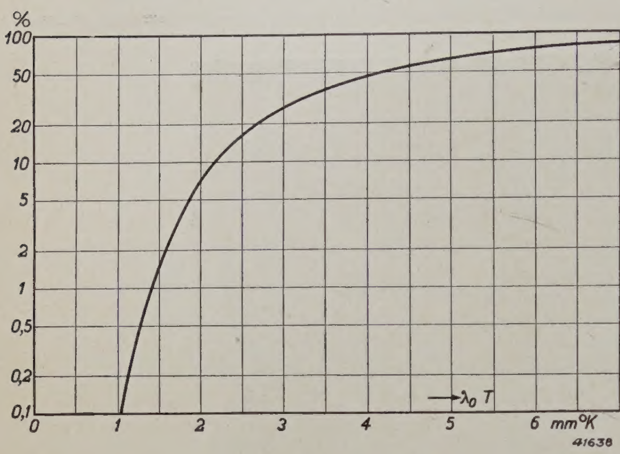

Fig. 1. Percentage of the radiation energy of a black body with a temperature T (°K) in the region of wavelengths shorter than λ_0 (mm) as a function of the product of λ_0 and T.

The unsensitized emulsion has a limiting wavelength of $\lambda_0 \approx 0.5 \times 10^{-3}$ mm, while the carbon filament lamp is used at a temperature of 2000°K. Thus $\lambda_0 T \approx 1$, and for this from fig. 1 it may be deduced that only about 0.8 per thousand of the energy radiated is actinically effective.

In the case of daylight the effective radiation energy amounts to about 25 percent and is thus 300 times as high. Since ordinary daylight possesses an intensity of about 300 W/m², an equivalent illumination with carbon filament lamps would possess an intensity of $300 \times 300 \approx 10^5$ W/m², [1]), which with an efficiency of 0.3 Dlm/W amounts to 300 000 lux! It is easy to understand that such an illumination can never be realized with carbon filament lamps, if only because of the heating of the illuminated objects. If the temperature is calculated which the illuminated objects must possess in order to dissipate the incident energy by radiation, a temperature of more than 1000° C is found.

The circumstances become much more favourable when light sources are used which radiate light of shorter wavelengths. If, for example, an electric arc is used with a colour temperature of 3800° K, the effective radiation energy (wavelength shorter than 500 mμ) amounts to about 6 percent of the total. Indeed already in 1903 it was found possible to take cinematographic pictures of interiors with the help of arc lamps and in this way to become independent of the weather and the position of the sun. Of course the intensity of illumination required, which on the basis of the above estimation would amount to about 10 000 lux, is still very considerable, but thanks to the great intensity of the electric arc this was not found to be a serious objection. In the end, in spite of certain inconveniences connected with its use, the electric arc was generally accepted and formed practically the only source of light used for making films. The incandescent lamp, although it was then already more suitable than the original carbon filament lamp, was for the time being not considered.

If we now consider the progress in photographic technique and in light technique during the early days of the film industry, we can recognize an attempt to bring the actinism curve of the film and the intensity curve of the incandescent lamp closer and closer to each other. The film, originally sensitive only to blue rays, was sensitized for yellow and later for red, whereby the limit of sensitivity was shifted to 600 and 670 mμ, respectively. On the other hand metals with higher and higher melting points came into use as filaments in the lamps, so that the temperature of incandescence could be raised from about 2000° K to about 3000° K. The radiation of the lamp in this way became richer and richer in light of short wavelengths.

In *fig. 2* several stages of this development are given by plotting for various years the intensity curves of the incandescent lamps then in use and the sensitivity curves of the then available types of film. It is immediately evident that the common spectral region of the two curves has become much larger in the course of these years. The actinic part of the radiation energy has increased from 0.8 per thousand to 8 percent, so that the illumination energy required has become a factor 100 smaller. Actually the progress is even greater than would be concluded from this, because simultaneously with the film and incandescent lamp the film camera was also improved. This improvement is difficult to indicate in figures, since the large lens apertures which are now at our disposal cannot be used under all circumstances because of the required depth of focus. It may, however, be said that the reduction in the amount of light required thereby achieved is not estimated too low at a factor 5. According to our calculation, therefore, the intensity of radiation at present still necessary would amount to

[1]) This value can of course only represent a rough estimation of the required illumination intensity, since the actual light requirements are entirely dependent upon the scene to be rendered.

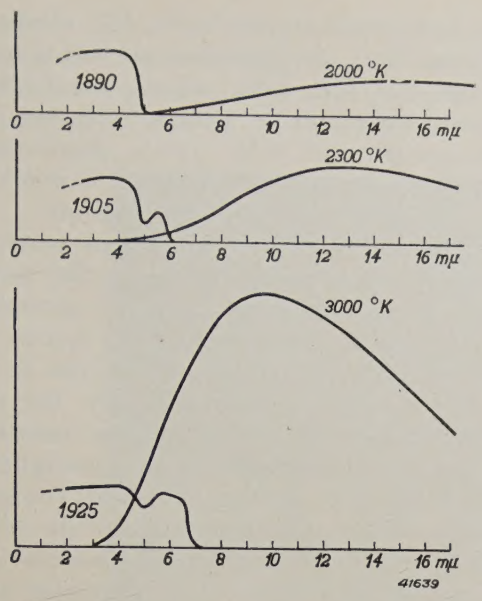

Fig. 2. Spectral distribution of the intensity of various incandescent lamps developed at different successive periods, and spectral sensitivity curve of different photographic materials which were successively put on the market. The effective part of the radiation has increased in the course of time from 0.8 per thousand to 8 percent.

$$\frac{10^5}{5 \cdot 100} \approx 200\ \mathrm{W/m^2}, \text{ or about } 5000 \text{ lux},$$

and this is an illumination intensity which can easily be attained.

The time at which the use of incandescent lamps in the film studio began to be a practical possibility was around 1925. By this time the work in film studios had already reached such an an extent that the much more convenient manipulation of the incandescent lamp (compared with the carbon arc) made its adoption attractive. Another important advantage of the incandescent lamp is its absolutely constant and quiet operation, which is very important for players and operators. The danger of flicker or extinction at critical moments of the scene, which with the carbon arc sometimes results in faulty exposures, is absent with the incandescent lamp. The repetition of scenes due to incorrect exposure therefore need not occur. Even with the usual alternating current supply the light emission of the incandescent lamp is practically constant since the thick filament of the large lamps used for illuminating the film studio possesses a sufficiently large heat capacity to equalize the fluctuations of the energy supply. Because of this, with incandescent lamps there is no danger of stroboscopic effects. With arc lamps, in order to exclude this danger, it was often necessary to use direct current. The latter is obtained by means of motor aggregates, which considerably increase the installation costs.

Further advantages of the incandescent lamp are the following :

1) Simple and cheap operation (no adjustment of the carbons).
2) Ease of transportation of the lighting apparatus.
3) Less danger of fire.
4) Less danger of inflammation of the eyes due to ultra-violet radiation.

The advantages of the incandescent lamp as a source of light for film making were further added to when the sound film made its appearance. Attempts were of course then being made to silence the hissing, sputtering arc, but no complete and reliable success had been achieved, so that the cause of the silent incandescent lamp was quickly won.

The task of the lamp manufacturers now consisted in developing incandescent lamps suitable for the illumination of film studios. In the following we shall give an outline of some of the fundamental problems which were encountered in this development. We shall then discuss the construction and use of the existing film studio lamps and finally the limits of the field of application of the incandescent lamp in the film studio.

Spectral distribution of the light and lifetime

As we have seen, for securing sufficient actinic effect it is desirable to choose the temperature of the filament as high as possible. With every increase of the temperature, however, the life of the filament is shortened and therefore a halt must be called at a certain temperature in order to prevent the use of incandescent lamps for film-making from becoming uneconomical. A life of 100 hours forms a satisfactory compromise. Evaluated according to the actinism of a panchromatic plate, the incandessent lamp with this life delivers about twice as much light as with the life customary for ordinary illumination purposes [2]). The temperature of the filament is about 200° higher than in the case of a life of 1000 hours, and with large lamps amounts to about 3200° K. The content of blue and yellow radiation is high enough at this temperature, so that films can be made not only with panchromatic material but also with orthochromatic material.

When working with colour films, which are at present less sensitive, on the other hand, the actinic effect of the radiation is still on the low side with a colour temperature of 3200°K. Added to this is the fact that the spectral composition of the light at the tempe-

rature mentioned is not entirely suitable for securing optimum colour rendering. Originally the emulsion of the colour film was so tuned that upon the use of arc lamps for projection as well as for photography colours are obtained which approximately resemble those seen by daylight. Later on, in connection with the use of incandescent lamps, the emulsion of the colour film was adapted to a lower colour temperature than that of the arc lamp. It was impossible, however, entirely to reach the colour temperature of the incandescent lamps and a compromise was chosen such that the optimum colour temperature of the lamp for the exposure is higher than 3200° K. This resulted in the acceptance of a shorter life than 100 hours for lamps used for taking colour films.

In practice incandescent lamps with a life of 25 hours and a temperature of about 3300°K are used, which means a colour temperature of 3375°K. If a still higher colour temperature is required it is realized by means of filters, since otherwise the life would probably be much too short. It is clear that the use of filters always involves a loss of light. This device is therefore avoided as much as possible.

Directions for the use of the incandescent lamp in film studios

Just as in the case of the utility illumination of office buildings and factories, a distinction can be made in the illumination of a film set between the general illumination and the local illumination. The general illumination serves to imitate reality as far as light and shadow are concerned; the purpose of the local illumination is usually to produce artistic effects and for instance to focus the attention upon a certain object. The view of a film studio in *fig. 3* provides striking examples of both methods of illumination.

The way in which the camera man works with general or local illumination depends very much upon his personal taste, so that it is very difficult to give generally valid rules. One director prefers a balanced rendering of a whole set, another desires to focus the attention of the audience upon a definite point in every picture. The former will prefer a fairly uniform illumination of the whole, while the latter will keep the general illumination low in order to be able to accentuate the most important details of the picture the more strongly by means of spotlights. He will usually depend entirely upon his own visual impression, since light measurements in the studio take too much time. An exception to this is made in the case of colour films, which, due to the properties of the emulsion, permit much less play in the exposure and with which, moreover, the camera man has not yet obtained as much experience as with black-and-white films.

A result of these very divergent methods of illumination is a great variety in the technical devices used. Nevertheless, some attempt will be made to make some restrictions and to design lamps and lighting fixtures which can as far as possible be used universally. By the above-mentioned division of the lighting installations into general illumination and spotlights this object is found to be best achieved: the general illumination has relatively little to do with the artistic part of the problem of illumination, so that certain general guiding principles can be applied to it. On the other hand the spotlights are so constructed that they are easily transported and adjusted, so that with relatively little variation of the lighting apparatus a great variety of methods of illumination is possible. In the following we shall discuss the most important constructions for the two lighting systems.

General illumination

The required intensity of the general illumination depends upon many factors, such as the nature of the object to be photographed, the lens aperture of the camera used, the transport velocity of the film, the sensitivity of the emulsion and the process of development chosen. The intensity of the accentuation by spotlights which are to be used in addition to the general illumination will also be of importance for the general level of illumination.

Ordinarily with indoor scenes illumination intensities between 1000 and 4000 lux are used. In landscape sets (built up in a film studio) higher intensities of illumination, for instance 10 000 to 14 000 lux, are used. From this it follows that very many lamps will be needed for the general illumination, especially since it is advisable not to use too large units with a view to securing a uniform light distribution.

The lamps are mounted side by side in a diffusely reflecting bank or separately in fixtures which are combined to form batteries. These banks or batteries are placed in front of, beside or above the scene to be photographed, *Fig. 4* shows an example; in this case a number of "Argaphoto" lamps[3]) with the corresponding reflectors (type SC 255) are combined to form a battery illuminating the scene to be filmed

[2]) The power supplied to the lamp increases by about 40%; the further improvement is due to the increase in the actinism of the radiation emitted. For data on this subject see the article: Lamps for use in Photography, Philips Techn. Rev. 6, 259, 1941.

[3]) For the "Argaphoto" lamp and the "Photomirenta" lamp see the article referred to in footnote [2]).

from above. The intensity and the concentration of the beam formed can be varied by a special arrangement. For this purpose the toothwheel E is rotated whereupon the rods Z and D, respectively, for the outer and inner ring of lamps, are so manipulated that the individual reflectors are directed more or less toward the outside.

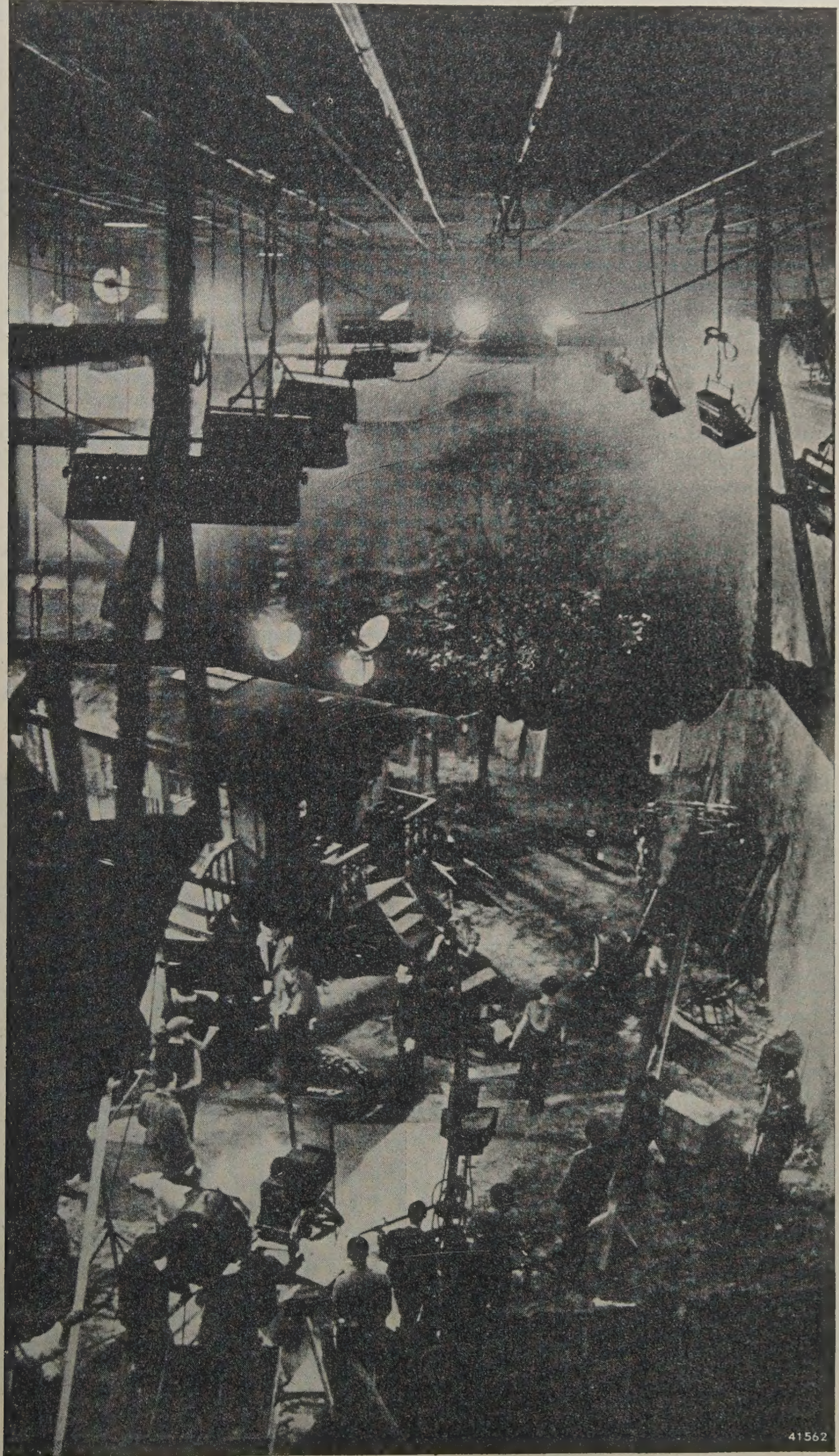

Fig. 3 View of a film studio. Hanging from the ceiling may be seen numerous lights for the general illumination, while a number of spotlights for local illumination are seen on the ground.

Instead of "Argaphoto" lamps, "Photomirenta" lamps, also of 500 W, can be used .The reflectors are then superfluous since the "Photomirenta" lamp itself contains a reflector in the form of an internal silver mirror as rear wall. Finally tubular incandescent lamps can also

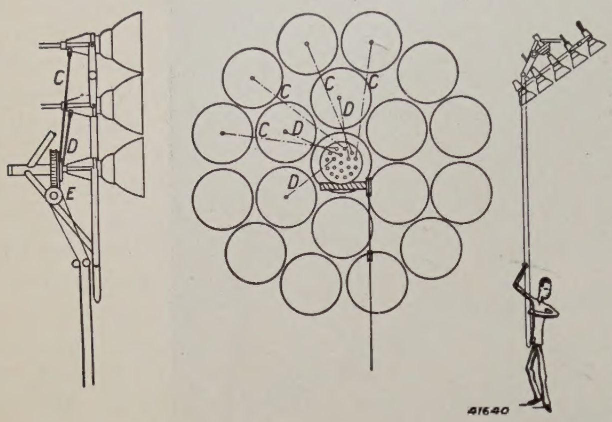

Fig. 4. Battery of "Argaphoto" lamps for general illumination.

very well be used for the general illumination. These lamps with their linear filament are especially suitable for obtaining a uniform illumination. Suitable models for film studio illumination are the "Linea" lamps of 250, 500 and 1000 W (see *fig. 5*).

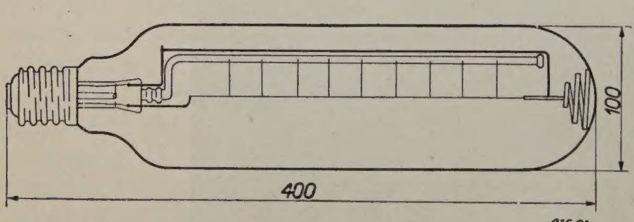

Fig. 5. The "Linea" lamp of 1000 W for general illumination of film studios.

In this connection it may be noted that the oldest type of the low-pressure mercury lamp,the so-called "Cooper-Hewitt" lamp, has a form very much resembling that of the "Linea" lamp. In the early days of film technique when emulsions were much less sensitive, so that it was very difficult to obtain sufficiently strong illumination, use was in fact made of the very good actinic effect of mercury light. This use of the mercury lamp began in 1909. Later, when red-sensitive films were brought on the market, the advantage of the mercury lamp was of much less significance. Since, moreover, the incorrect colour rendering under mercury light was felt more and more as an objection as the requirements as to quality increased, the use of the low-pressure mercury lamp in film studios was given up entirely.

In recent times, however, the use of the low-pressure mercury lamp has experienced a vigorous revival due to the appearance of mercury-discharge lamps with fluorescent tubes. These so-called TL lamps [4]) can be manufactured with a spectral composition which very nearly resembles that of daylight and which is very suitable for cinematographic purposes.

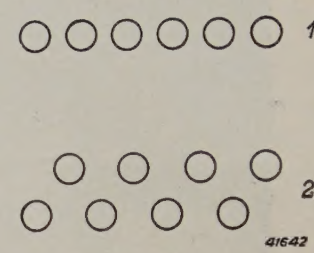

Fig. 6. Arrangement of the parts of the helix in the single-plane filament and in the bi-plane filament.

Spotlights

For spotlights lamps with a small filament are needed. In order to obtain a beam of perfectly parallel rays, these rays would have to start from the focus of some kind of optical system consisting of lenses or parabolic mirrors or a combination of the two. Since, however, exact parallelism of the rays in the beam is not required

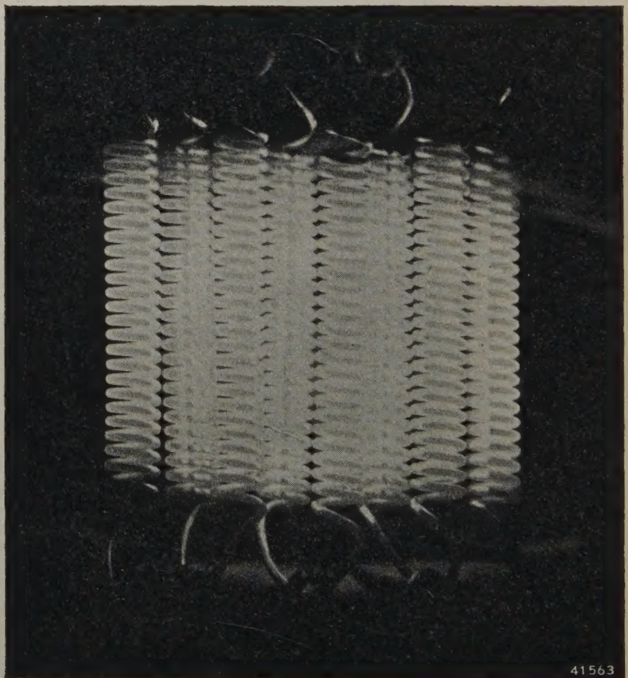

Fig. 7 The bi-plane filament seen from the front. The two groups of helixes supplement each other to give a homogeously luminous plane.

[4]) See Philips Techn. Rev. **3**, 272, 1938; **4**, 337, 1939; **6**, 65, 1941.

and is even undesired in connection with the sharpness of shadows, a certain amount of space around the focus is available for the filament. If the optical system is not to become too large, however, this space remains so limited that it is desirable to concentrate the filament as much as possible.

The way in which attempt are made to realize this concentration of the filament depends upon the desired light distribution over the cross section of the beam. Most film studio lamps are made with single coils, which are placed as shown in *fig. 6* in one plane or in two planes one behind the other. In the latter case a very high average brightness is obtained in the direction perpendicular to the plane of the coils, since the luminous plane can be practically entirely filled with incandescent wires (see *fig. 7*). Upon deviation from this direction, however, the brightness decreases more rapidly than for a single-plane filament, since the coils then partially overlap.

The ordinary powers of the lamps for spotlights are 500, 1000, 2000, 3000, 5000 and 10 000 watts. In order to keep the dimensions of the bulb as small as possible in the high-power lamps, which is of importance for the construction of the fixtures, the bulbs of the types for more than 500 W are made of hard glass. Two examples of the construction of the 5000 W film studio lamp with single-plane filament are given in *fig. 8*. Attention is called especially to the unusual inner construction, the object of which is to make the lamp mechanically as strong as possible. The holder is provided with two pins, which if desired may be replaced by flexible cables.

In the construction reproduced in *fig. 8a* it may be seen that there is quite a long section below the bulb, namely the neck and the holder. By using a modern technique of fusing in, in which the copper pins, which serve simultaneously for fastening and current supply, are fused directly to the glass, this section could be made much shorter (see fig. *8b*). In spite of the fact that the coefficients of expansion of hard glass (40×10^{-7} per degree) and copper (180×10^{-7} per degree) are very different, this seal can easily be made provided the upper edge of the collar of the pin is made sufficiently thin to be deformed before the deforming forces give rise to intolerable stresses in the glass.

A disadvantage of the small dimensions of the bulb is that owing to the deposition of sputtered tungsten the surface of the glass is more strongly blackened in the course of time than in the case of ordinary lamps. At the end of the life of the lamp the absorption means not only an important loss of light but results at the same time in an extra heating of the bulb wall, which

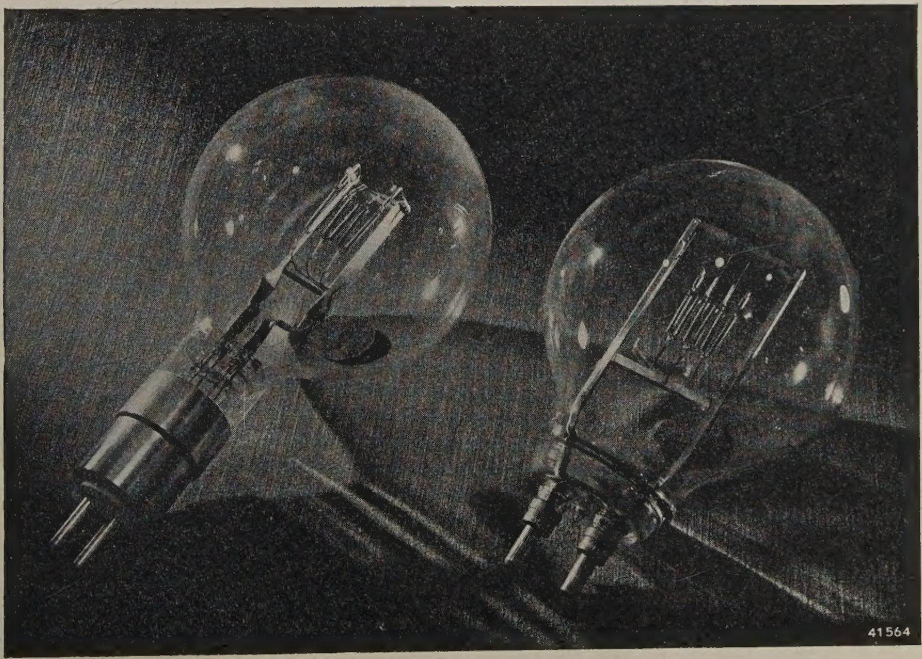

Fig. 8. Two models of the 5000 W film studio lamp with single-plane filament. In type *a*) the bulb has a fairly long neck. This could be very much shortened by fusing the pins directly to the glass (type *b*). The metal powder in the bulb (tungsten) serves to scour the blackness off the inside of the bulb. The diameter of the bulb is about 200 mm.

is greater the smaller the diameter of the bulb. This sets a limit to the reduction of the diameter.

In order to prevent loss of light and to be able to make the lamps smaller, a metal powder is introduced into the lamp to scour the sputtered material from the bulb wall upon shaking. This metal powder can clearly be seen at the bottom of the bulbs of the film studio lamps shown in *figs. 8a* and *b*.

The most commonly used optical systems for concentrating the light of the film studio lamps are the following:

1) Smooth parabolic mirrors. These give a narrow powerful beam. A disadvantage, however, is that it is difficult to prevent the image of certain parts of the coils from being projected somewhere in space. If an actor accidently occupies that position, the contours of the filament become disturbingly visible in the picture.

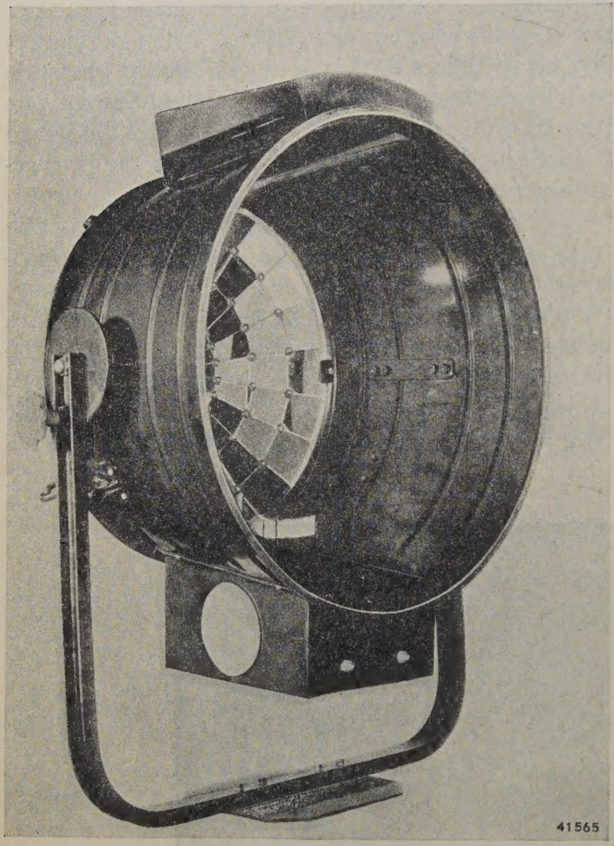

Fig. 9. Parabolic mirrors for film studio lamps. The curved mirror surface is replaced by a number of facet mirrors in order to prevent a sharp projection of the image of the filament.

2) Apparatus in which parabolic facet mirrors are mounted (see *fig. 9*). Small plane mirrors are fastened to the parabola and a broad uniform beam is obtained. *Fig. 10* shows the light disstribution of such a spotlight with a film studio lamp of 115V, 5000 W.

3) Apparatus in which a combination of spherical mirrors and Fresnel lenses [5]) is used (see *fig. 11*). The spherical mirror provides that the spaces between the various coils of the single-plane filament are filled by the mirror images of these coils. When a bi-plane filament is used this mirror is unnecessary. *Fig.* 12 shows a model of such an apparatus with a film studio lamp of 3000 W. This construction is the most complicated, but it also has the highest efficiency. About 20 percent of the light emitted is concentrated into a beam by the apparatus shown, while the parabolic mirror with facets shown in fig. 9 has an efficiency of only 9 percent.

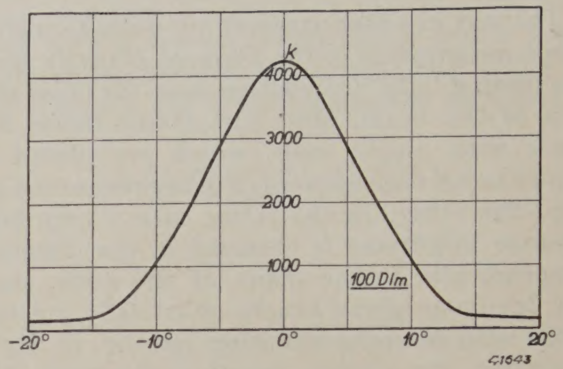

Fig. 10. Light distribution over the cross section of the beam which is obtained with the help of the reflector shown in fig. 9 and a film studio lamp with single-plane filament (115 V, 5 kW).

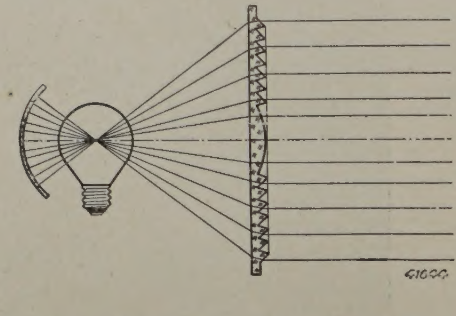

Fig. 11. Beam formation of the light of an incandescent lamp with a spherical mirror and a Fresnel lens.

Several light sources for special cases

Although the lamps described in the foregoing are already reasonably well adapted to the requirements made in a film studio, there are, however, special cases in which these lamps are less suitable.

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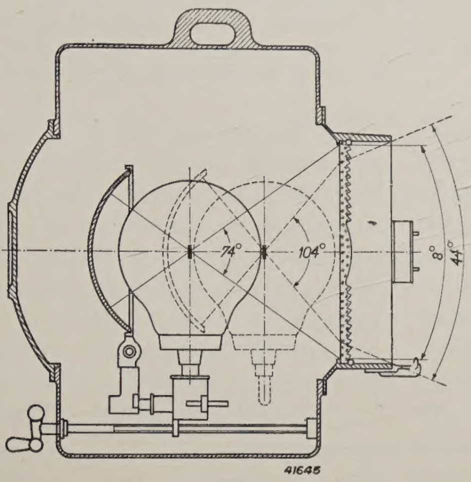
[5]) A detailed description of the Fresnel lens may found in the article: Lamps for Lighthouses, Philips Techn. Rev. 4, 33, 1939.

One of the limits set for the use of the film studio lamps described is connected with their heat development. This restricts the intensity of illumination with these lamps to about 20 000 lux, since a more intense radiation begins to hurt the skin. But even when this limit has not been reached, the temperature in the studio may rise intolerably due to the great energy dissipation. In order to combat this a water-cooled studio lamp has been designed (see *fig. 13*). A glass envelope surrounds the lamp and the water flows between this envelope and the bulb. The greater part of the infra red-radiation is absorbed by this water jacket, while hardly any light is intercepted.

Another case in which the film studio lamps are inadequate occurs when an intense beam of relatively small cross section is required. The dimensions of the filament of the ordinary film studio lamps are then still too large for the object in view. A decided improvement is obtained by replacing the single coil filament by a coiled-coil filament. A film studio lamp with coiled-coil filament is shown diagrammatically in *fig. 14*; it may at the same time be seen from this figure how the lamp is placed in the reflector. In this low-voltage lamp the brightness of the filament amounts to 25 cp/mm², while with ordinary film studio lamps (for instance 110 V 3000W) a brightness of only 15 cp/mm² is obtained.

When the requirements of light intensity or concentration of the beam are very high, it may occur that the object in view cannot be achieved at all with incandescent lamps. In such cases one may return to the carbon arc lamp, which possesses a much smaller luminous surface with the same light flux. If because of the objections



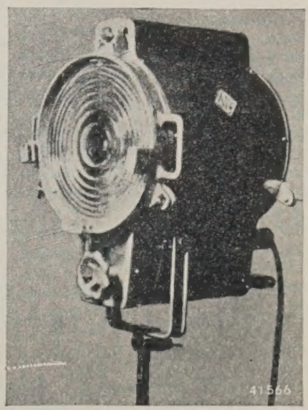


Fig. 12. Reflector with Fresnel lens for film studio lamps. This construction has about twice the efficiency of the spotlight with parabolic mirror.

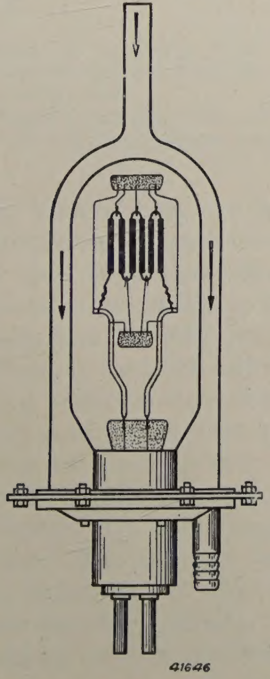


Fig. 13. Film studio lamp with double envelope for water cooling.

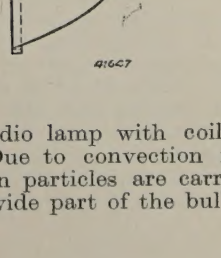


Fig. 14. Film studio lamp with coiled-coil filament (24V, 1000 W). Due to convection in the bulb the sputtered tungsten particles are carried upward and deposited in the wide part of the bulb.

mentioned it is not desirable to use a carbon arc lamp, there is at present the possibility of using water-cooled mercury lamps of super high pressure. In contrast to mercury lamps of low pressure the high-pressure mercury lamps give a practically white light which can be used without hesitation for making black and white films. With this new light source, the brightness of which corresponds approximately to that of the high-intensity arc lamp, experiments have been carried out continuously during recent years. In addition to the uniform and noiseless performance another special advantage is the small proportion of infra-red radiation, so that an intense illumination with mercury lamps has a much smaller heating effect than the same illumination with carbon arc lamps.

STABILITY AND INSTABILITY IN TRIODE OSCILLATORS

by J. VAN SLOOTEN.

621.396 : 615.1

The state of a triode oscillator whose grid voltage is obtained by means of a condenser and a leakage resistance can be characterized for any moment by the value of the bias (V_g) and the value of the oscillator amplitude (W). Graphically, therefore, the state can be characterized by a certain "operating point" in a W-V_g diagram. Each point of the diagram represents a possible operating state. In general, however, this is not stationary, for in the course of time the operating point will shift. This movement is investigated in detail in this article, and the possible stationary states automatically become evident, while at the same time it becomes clear how the oscillator reaches the stationary state. In certain cases the possible trajects of the operating point do not approach the stationary state but converge to a fairly large loop enclosing this state. One then speaks of blocking of the oscillator. The circumstances under which this blocking occurs are studied in detail. It is found that the chance of blocking can be reduced by making the grid current characteristic of the oscillator triode as steep as possible.

In a previous article in this periodical [1]) we devoted a detailed consideration to the way in which the adjusment of a triode oscillator to a stationary state of operation is achieved. There we confined ourselves to a discussion of the simplest connections, which are represented by *figs. 1a* and *b*. In the system *a* the control grid bias is taken from a potentiometer, while in the system *b* it is obtained by means of a grid condenser and a leakage resistance.

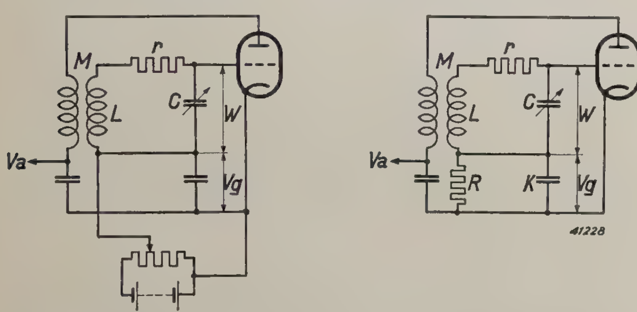


Fig. 1. Diagram of oscillator with triode.
a) The grid bias is excited with the help of a battery and a potentiometer.
b) The grid bias is excited with the help of the grid condenser K and the leakage resistance R.

The latter connections are by far the more important technically, and from the theoretical point of view they also offer the most interesting aspects. One of their remarkable properties, which was already pointed out in the previous article, is that the adjustment to a certain operating point can be stable or unstable according to the magnitude of the grid condenser K. In this article we shall go into the question of the stability or instability of a triode oscillator more thoroughly. We shall begin with a short résumé of what has already been written on this subject, referring for the arguments concerned to the previous article.

The behaviour of the oscillator can best be characterized by plotting in a diagram the amplitude W of the oscillator voltage as a function of the grid bias V_g. In the case of connections *a* this diagram may simply be recorded experimentally by setting the grid bias at different values with the help of the potentiometer and measuring the values of the oscillator voltage which then occur. In the case of connections *b*, on the other hand, the grid bias cannot be chosen arbitrarily, for it adjusts itself automatically to a certain value depending upon the grid resistance R[2]).

Thus in order to record the W-V_g diagram the grid resistance must be varied. When the grid resistance is varied (beginning with small values) the negative grid voltage also rises in the stationary state. Remarkably enough, however, a maximum is then reached for a certain grid resistance and, upon further increase of R, V_g begins to decrease again.

The same holds qualitatively for the oscillator voltage W. With increasing values of R the oscillator voltage first increases, the relation between W and V_g being exactly the same as in the case of direct adjustment of the bias with the help a of potentiometer. When, however, the grid voltage begins to fall again upon further increase of R, the oscillator voltage does **not** follow the same curve in the W-V_g plane but passes through appreciably lower values. This is shown clearly in the diagram reproduced in *fig. 2*.

1) Philips Techn. Rev. **7**, 40, 1942

2) The grid bias in the stationary state always has a negative value which is slightly less than the amplitude W of the grid AC voltage, so that during a small part of the period the total grid voltage is positive. Only during that part of the period does any appreciable grid current flow. The condenser K is charged by these current impulses, while at the same time it is continuously discharged by the resistance R. The bias adjusts itself automatically to such a value that during a whole period the discharge is equal to the charge in each current impulse. This adjustment is independent of the capacity K, provided the latter is not too small.

An explanation of this remarkable behaviour was given in the article referred to in footnote [1]) by examining for every value of V_b the manner in which the slope S_b necessary for oscillation and the "effective" slope S_{eff} vary

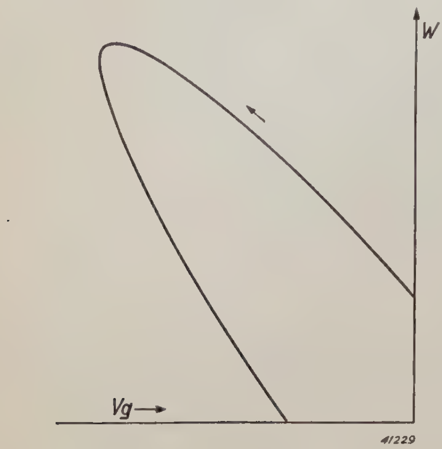


Fig. 2. W-V_g diagram of oscillator connections. Points on the line drawn represent possible stationary states of the oscillator connections according to fig. 1*b*. Upon enlarging the leakage resistance R the curve is traced in the direction of the arrow.

as functions of the oscillator voltage. If, the effective slope is greater than the slope necessary for oscillation the amplitude of the oscillation will increase, while in the reverse case it will decrease. A stationary value of the amplitude must thus correspond to a point of intersection of the curves representing S_b and S_{eff} as functions of W.

Now the curves for S_b and S_{eff} at the ordinary values of the grid bias exhibit the form shown in *fig. 3*, there being two points of intersection B and A. The values of W corresponding to these two points of intersection are found to correspond to the oscillation amplitudes which are observed with a given value of V_g respectively on the ascending and descending branches of the curve for the motion of the stationary operating point in the W-V_g diagram.

In this way the remarkable form of the W-V_g diagram can be explained in principle. Various questions, however, still remain open for discussion. While the stability of a stationary state on the upper branch of the curve in the W-V_g diagram is immediately ensured, this is not the case on the lower branch (point A). It is easily understood that the intersection point A, at a constant value of the bias, *i.e.* in connections according to fig. *1a*, represents a labile adjustment. If, for example, due to an accidental fluctuation the oscillation amplitude is made slightly greater than corresponds to the intersection A in fig. 3, the effective slope S_{eff} will become greater than the required slope S_b, so that the oscillation amplitude will further increase and therefore not return to the stationary value. The same labile behaviour is found for a fluctuation in the opposite direction.

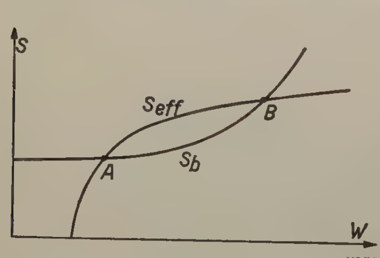


Fig. 3. Required slope S_b and effective slope S_{eff} as functions of the amplitude W of the oscillation. The slopes depend actually not only on W but also on the grid voltage V_g. In drawing this diagram a given constant value of V_g has been assumed.

On the other hand, in the case of the oscillator connections with grid condenser and leakage resistance it is found that the adjustment to the operating point A may be stable under certain circumstances. When, for example, in these connections the amplitude W deviates from the stationary state due to a fluctuation, this results, as far as the further behaviour of the oscillation is concerned, not only in a change in W but also in a change in V_g, and in the previous article we have attempted to prove that this change in V_g has a stabilizing effect. In this article we shall now study in more detail the motion of the state point of a triode oscillator in the W-V_g plane in order to obtain a more accurate insight into the conditions under which this stabilizing effect is sufficient to make a stationary adjustment possible.

The behaviour of the operating point in the W-V_g plane

In order to investigate the character of the motion in the W-V_g plane, we shall first determine the factors which may cause the grid voltage V_g to change. To each set of values of W and V_g there belongs a certain value $\bar{i}_g$ of the average grid current. In order to keep in mind that this value is a function of W and V_g we indicate it by $\bar{i}_g\ (W, V_g)$.

The current through the leakage resistance R in fig. 2 is given by

$$i_R = \frac{V_g}{R}.$$

It is now clear that the condenser K is charged by an average current.

$$i_K = \bar{i}_g\ (W,\ V_g) - i_R.$$

As a result the condenser voltage varies according to the known law:

$$\frac{\mathrm{d}V_g}{\mathrm{d}t} = \frac{i_K}{K} = \frac{1}{K}\left\{\overline{i_g}\ (W,\ V_g) - \frac{V_g}{R}\right\} \quad . \ . \ . \ . \quad (1)$$

This equation, in which the negative grid voltage is considered as a positive quantity, describes the manner in which V_g varies. To this we shall add a second equation describing how W will vary. To do this we make use of the theorem that the AC voltage in a damped L-C circuit with the series resistance r in free oscillation decreases according to

$$\frac{\mathrm{d}W}{\mathrm{d}t} = -W\,\frac{r}{2L},$$

which result is obtained by differentiating the familiar expression

$$W = W_0 e^{-\frac{r}{2L}t}$$

with respect to time.

Now the series resistance present in the oscillation circuit is equal to the resistance of the circuit r decreased by the negative damping which occurs in the oscillation circuit as a result of the back coupling and which can be represented in the diagram by a negative resistance in series with the oscillator coil. Expressed by the usual symbols this negative resistance is given by

$$r' = \frac{M S_{eff}}{C} \quad . \ . \ . \ . \ . \quad (2)$$

M is here the mutual induction of back-coupling coil and circuit coil, while S_{eff} represents the effective slope, which is a function of W and V_g.

Besides the resistance r of the circuit itself and the negative resistance r' still a third resistance appears due to the damping resulting from the flow of grid current. Since, however, this grid current is very small at the ordinary adjustment of the oscillator, we may disregard its damping effect[3]). The equation for the variation in W thus becomes:

$$\frac{\mathrm{d}W}{\mathrm{d}t} = -\frac{r-r'}{2L}\,W \quad . \ . \ . \ . \ . \ . \quad (3)$$

We can now eliminate the time variable $\mathrm{d}t$ immediately from (1) and (3) and we then obtain:

$$\frac{\mathrm{d}V_g}{\mathrm{d}W} = -\frac{2L}{KW}\,\frac{i_g\ (W,\ V_g) - \dfrac{V_g}{R}}{r-r'\ (W, V_g)} \quad . \ . \ . \ . \ . \quad (4)$$

By $r'\ (W, V_g)$ is meant that the above-defined resultant negative resistance r' (like Ig) is a fuction of W and V_g. From equation (4) it therefore follows that for each set of values of $W$and V_g, thus for every point in the W—V_g diagram, the direction in which the operating point moves is determined.

When these directions have been determined the solution of the differential equation (4) consists in drawing a smooth line which everywhere follows the local direction.

Although it would be a complicated business to indicate completely the directional field in the W-V_g plane, its qualitative character can be very simply determined. For this purpose we indicate the lines where $\mathrm{d}W/\mathrm{d}t$ and $\mathrm{d}V_g$-$\mathrm{d}t$ respectively are zero. On the first mentioned line W remains constant, while V_g may vary: the operating point is thus displaced horizontally. In the same way it may be seen that the last mentioned line is the locus of all points where the directional field is vertical. Any points of intersection of the curves $\mathrm{d}W/\mathrm{d}t = 0$ and $V_g/\mathrm{d}t = 0$ represent operating points for which both W and V_g are constant: these operating points are thus stationary working states which may or may not be stable.

The line $\mathrm{d}W/\mathrm{d}t = 0$ is determined by the relation already discussed between W and Vg in fig. 2, which is again reproduced in fig. 4 by curve I. Along this line the required slope is equal to the effective slope and is the condition for the constancy of the amplitude of the oscillation. In the region enclosed by the curve $S_{eff} > S_b$, *i.e.* the oscillation is built up ($\mathrm{d}W/\mathrm{d}t > 0$), while outside the curve I $S_{eff} < S_b$ and therefore $\mathrm{d}W/\mathrm{d}t < 0$.

In order to determine the line $\mathrm{d}V_g/\mathrm{d}t = 0$ we must ask what value V_g finally assumes

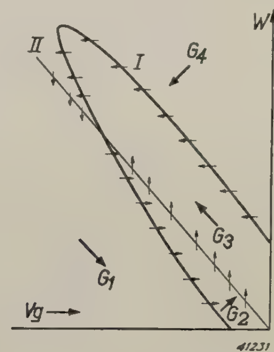


Fig. 4. W-Vg diagram of oscillator connections. Curve I, which is also drawn in fig. 2, represents the locus of all points with stationary oscillator amplitude W; curve II represents the locus of all points with stationary grid bias V_g. The point of intersection indicates the stationary working state. The arrows indicate the direction in which the operating point moves in the different regions.

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[3]) In principle this effect can also be taken into account by including the grid current damping in the total (negative) damping resistance r' of the triode. In that case equation (2) would have to be replaced by a more complicated expression. For the less usual adjustments on the upper branch of the curve in the W-Vg plane this correction is important.

with a given value of W. This will depend upon the magnitude of the leakage resistance. If the leakage resistance is infinitely large, the required curve is a straight line at an angle of 45° to the V_g-axis. A stationary adjustment is only reached when the condenser K is charged to such a point that the negative bias V_g is equal to the peak value W of the AC voltage. If the leakage resistance is not infinitely large the line is steeper and has, for instance, the shape indicated by curve *II* in fig. 4. It will be clear that in the region lying under line *II* the grid current is smaller than the current through the leakage resistance, so that the condenser is discharged ($\mathrm{d}V_g/\mathrm{d}t \vee 0$). In the same way in the space above line *II* $\mathrm{d}V_g/\mathrm{d}t < 0$.

On the basis of these properties of curves *I* and *II* we can now distinguish four regions in the W-V_g plane, which are indicated in fig.4 by G_1 to G_4 inclusive and are bounded as follows:

G_1	below	curve *II*	and outside	curve	*I*
G_2	,,	,, *II*	and inside	,,	*I*
G_3	above	,, *II*	and inside	,,	*I*
G_4	,,	,, *II*	and outside	,,	*I*

In these four regions the operating point of the oscillator will move in different ways and, as will be clear from the foregoing, it will move in the direction of the large arrows drawn in fig. 4. Each of these four arrows thus represents a region of directions which includes an angle of 90° between the horizontal and the vertical. The small arrows cutting the curves *I* and *II* indicate the direction in which the boundaries of the regions are passed.

Examples

With the help of the directions of motion in the W-V_g plane thus found we shall now examine what happens when the oscillator is left to itself with given but otherwise arbitrary values of W and V_g. In practice such an initial state could be realized by placing a battery in parallel with the condenser K and impressing on the L-C circuit a certain value of W by coupling with a generator which produces an oscillation of the same frequency as the oscillator. If the battery and the generator are now removed simultaneously, the oscillation then begins with these given values of W and V_g. A moment later, however, other values of W and V_g will have adjusted themselves, whereby the operating point in the W-V_g plane always follows the arrows of the field of directions.

As a first example we shall consider an oscillator whose grid resistance R and condenser K are very large. It is found experimentally that with such an oscillator no stationary working state is possible, but b l o c k i n g occurs. The oscillation begins to build up, the amplitude W and the negative bias V_g both increasing. The maximum of W, however, is quickly reached and a moment later the oscillation breaks off ($W \to 0$). The condenser K is then discharged *via* the resistance R, so that V_g also decreases again. The operating point in this case moves in the W-V_g diagram along the V_g-axis, as indicated in *fig. 5* by the arrow. At a given moment it will pass curve *I* and in doing so enter the region in which the oscillation of the oscillator can automatically build itself up. From that moment the value of W will again increase.

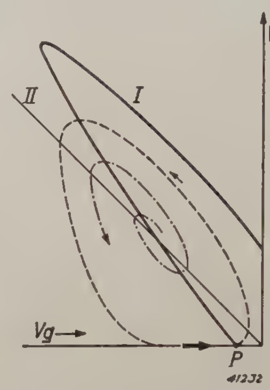

Fig. 5. Motion of the operating point in the W-V_g plane with a large value of the grid resistance R and the grid condenser K. The paths converge to a closed loop; a stationary adjustment is not reached.

The resulting motion of the operating point is indicated by the broken-line curve. As may be seen, the arrow direction dicussed in connection with fig. 4 has everywhere been followed. Typical of blocking, therefore, is the fact that the AC voltage decreases to a very small value before the grid condenser has been sufficiently discharged to cause the oscillation to be built up again.

Under the circumstances considered (large values of R and K) the path of the operating point also passes over to the broken-line curve when it is left to itself at a point of the W-V_g plane not lying on this curve[4]). If for example, the path of the operating point begins somewhere inside the closed loop, it will then describe a spiral towards the outside which finally passes over into the loop. A quantitative formulation of the condition under which this phenomenon takes place will be given later in this article.

[4]) The mathematically-minded reader will have noticed that the closed curve which the oscillator point describes upon blocking represents a "cycle limit" of the differential equation for the motion of the operating point.

Fig. 6 shows the shape of the path of the oscillator point when the grid condenser K is so far reduced that the oscillator becomes stable. The operating point in that case describes a spiral toward the inside from a given point in the W-V_g plane, which spiral approaches the stationary adjustment, namely the point of intersection of curves I and II. This point of intersection, since V_g as well as W is stationary, represents the only possible stable adjustment.

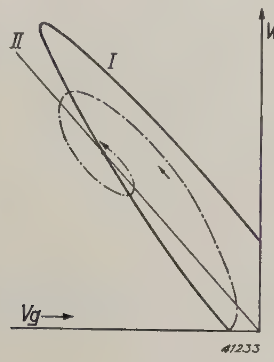

Fig. 6. Motion of the operating point in the W-V_g plane with a value of the grid condenser K smaller than in fig. 5. The operating point describes a spiral which converges towards the stationary state.

The character of the motion of the operating point is again different when the grid resistance is chosen so small that the point of intersection of curves I and II of fig. 4 falls in the upper branch of curve I. It may be recalled from the previous article that an operating point on the upper branch of curve I is always stable and may be realized with the aid of a bias voltage battery instead of with a grid resistance.The diagram in question is now sketched in *fig. 7a*. It may be seen that, retaining the arrow directions indicated in fig 4, the operating point cannot leave region G_3 when it has once entered it. The operating point thus approaches the point of intersection asymptotically without moving around it as in fig. 6.

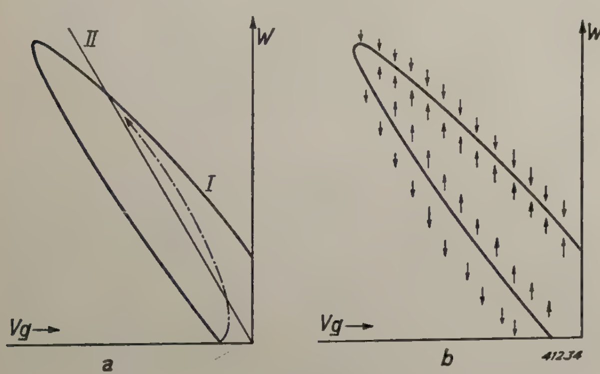

Fig. 7. *a*) Motion of the operating point with a low value of the grid resistance R. The stationary state is situated on the upper branch of curve I. It is reached without the operating point spiraling around it.
b) Motion of the operating point with oscillator connections with a fixed bias. The direction of the motion in the diagram is always vertical. Stable states are only possible on the upper branch of the curve.

If the bias is exit:d with a battery the field of directions in the W-V_g plane changes in the manner indicated in fig. *7b*. Each arrow of fig. *4* must now be replaced by its vertical component, since movements of the operating point in the horizontal direction do not now occur. It is clear from this diagram that the operating points on the upper branch of the curve are stable and on the lower branch labile.

Summarizing, three cases can be distinguished:

A) *Instability or blocking.* The operating point of the oscillator describes a closed curve in the W-Vg plane or approaches such a curve.
B) *Stability of the first type.* The operating point moves along a spiral towards the inside in the direction of the stationary state.
C) *Stability of the second type*, also to be realized with a fixed grid voltage. The oscillator point moves toward the stationary state from one side only.

For the sake of completeness it should be remarked that an intermediate case is possible between *A*) and *B*) in which in the case of a small deviation the stationary state is recovered by a spiral motion towards the inside, while a large deviation from the stationary state leads to a spiral motion towards the outside which passes over into the closed curve mentioned under A). This behaviour, of which *fig. 8* gives an indication, may also occur in practice, although it may be considered more or less a rarity.

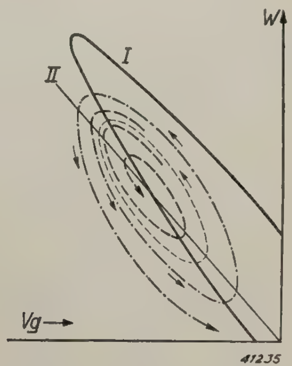

Fig. 8. Motion of the operating point with an oscillator in which, according to the initial point of the motion, blocking as well as stable oscillation may occur. Operating points inside the broken-line curve give a converging spiral, those outside a diverging spiral.

Calculation of the stabili'y

The foregoing considerations were of a somewhat qualitative nature. We shall now study

quantitatively the behaviour of the operating point of the oscillator in the immediate vicinity of the stable or unstable stationary state, in order to furnish evidence that the spiral motions towards the inside or towards the outside, can actually take place.

For this purpose we assume that the coordinates V_g and W of the operating point deviate by small amounts ΔV_g and ΔW from the coordinates of the intersection point of curves I and II representing the stationary adjustment. How will the operating point then move?

The change in V_g is described in general by equation (1). Since no change occurs in the point of intersection itself we obtain from this for small deviations

$$\frac{\mathrm{d}V_g}{\mathrm{d}t} = \frac{d\Delta V_g}{\mathrm{d}t} = \frac{1}{K}\left\{\frac{\delta \bar{i_g}}{\delta V_g}\Delta V_g + \frac{\delta \bar{i_g}}{\delta W}\Delta W - \frac{\Delta V_g}{R}\right\} \quad . \; . \; . \; . \quad (5)$$

In this equation the negative grid voltage V_g is again considered as a positive quantity. Connected with this is the fact that $\delta i_g/\delta V_g$ will be negative, since with constant oscillation amplitude W the grid current will decrease with increasing negative bias.

The change in the oscillation amplitude $(\mathrm{d}\Delta W/\mathrm{d}t)$ in the vicinity of the operating point can now be derived in exactly the same way as the change in the bias. From equation (3) it follows immediately that

$$\frac{\mathrm{d}W}{\mathrm{d}t} = \frac{\mathrm{d}\Delta W}{dt} = \frac{W}{2L}\Delta r' \quad . \; . \; . \quad (6)$$

As already mentioned, r' is here a negative substitute resistance which must be imagined to be in series with the coil of the oscillator circuit in order to represent the effect of the back-coupling coil and of the valve on the oscillator circuit. Since this negative resistance is given by equation (2), the following is true:

$$\Delta r' = \frac{M}{C}\left(\frac{\delta S_{\mathrm{eff}}}{\delta W}\Delta W + \frac{\delta S_{\mathrm{eff}}}{\delta V_g}\Delta V_g\right)$$

and by substituting this in equation (6) we obtain

$$\frac{\mathrm{d}\Delta W}{\mathrm{d}t} = \frac{WM}{2LC}\left(\frac{\delta S_{\mathrm{eff}}}{\delta W}\Delta W + \frac{\delta S_{\mathrm{eff}}}{\delta V_g}\Delta V_g\right) \quad . \quad (7)$$

Equations (5) and (7) together describe the behaviour of the oscillator upon the assumed deviation from the state of equilibrium. For the sake of clearness we write these equations of motion of the operating point in the form:

$$\left.\begin{aligned} \frac{\mathrm{d}\Delta W}{\mathrm{d}t} &= a\Delta W - b\Delta V_g \\ \frac{\mathrm{d}\Delta V_g}{\mathrm{d}t} &= c\Delta W - d\Delta V_g \end{aligned}\right\} \quad . \; . \; . \; . \quad (8)$$

Here a, b, c and d are quantities defined by (5) and (7) having positive values.

From the two equations (8) we may simply eliminate ΔW or ΔV_g. If we choose the latter we obtain for ΔW a differential equation of the second order:

$$\frac{\mathrm{d}^2\Delta W}{\mathrm{d}t^2} + (d-a)\frac{\mathrm{d}\Delta W}{\mathrm{d}t} + (bc-ad)\Delta W = 0,$$

while for ΔV_g exactly the same differential equation may be derived.

In the cases of interest to us $(bc-ad)$ is found to be positive[5]). The solutions of the differential equation then have the character of a sinusoidal oscillation whose amplitude varies with the time according to a power of e, namely proportinal to

$$e^{-(d-a)t}.$$

The spiral motion of the operating point is composed of two such oscillations of W and V_g shifted in phase. A stable adjustment is obtained when the amplitude of the oscillation decreases in the course of time, for which the condition that $d > a$ must be fulfilled, or written out in full :

$$\frac{1}{KR} - \frac{1}{K}\frac{\delta \bar{i_g}}{\delta V_g} > \frac{WM}{2LC}\frac{\delta S_{\mathrm{eff}}}{\delta W} \quad . \; . \quad (9)$$

From this it is immediately clear that the stability can be promoted by a reduction in size of the grid condenser K. Since $\delta \bar{i_g}/\delta V_g$ is negative it further follows from relation (9) that an increase in the slope of the grid current characteristic $(\delta i_g/\delta V_g)$ also has a favourable effect upon the stability [6]). The knowledge of the latter fact has led in practice to new constructions in oscillator valves, for example to the use of a control grid which is closely wound at its ends. The closely wound part draws a grid current at positive grid voltages but has no further effect on the characteristics of the oscillator valve.

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[5]) The condition that $bc\text{-}ad > 0$ means only that one is concerned with an intersection point on the returning branch of the characteristic. Referring back to fig. 2, we may then say that the slope of curve I is greater than that of curve II. These slopes are easily calculated with the help of equation (8). For curve I $\mathrm{d}W/\mathrm{d}t = 0$; this curve therefore has a slope $\triangle W/\triangle V_g = b/a$. In the same way one finds for the slope of curve II a value d/c. For a point of intersection on the returning branch therefore $b/a > d/c$ or $bc\text{-}ad > 0$.

[6]) In the graphical method of representation which we have employed in figs. 5 and 6 the stabilizing effect of a steep grid current characteristic can also be detected. If the curve for $\mathrm{d}W/\mathrm{d}t = 0$ (curve I) is drawn for a steep grid current characteristic, the loop becomes very narrow and the field of directions is so distorted that it becomes almost impossible to draw a spiral motion of the operating point towards the outside.

In connection with these practical consequences we shall go somewhat more deeply into the significance of the grid current characteristic. For that purpose we shall consider fig. 9, in which it is indicated how the negative grid bias and the grid AC voltage together determine the grid current. The relation between grid current and grid voltage is here represented by a broken straight line. The shaded area is a measure of the average grid current $\overline{i_g}$.

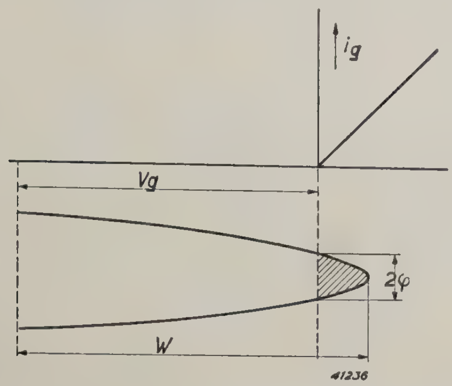


Fig. 9. Diagram for the calculation of the grid current for given values of the grid bias V_g and of the oscillator amplitude W.

For positive grid voltages in the approximation chosen here the grid current is proportional to the grid voltage, so that we may speak of a certain resistance R_i between cathode and control grid. If, further, we indicate by 2φ the phase angle of the part of the period during which grid current flows (see fig. 9) then the average grid current follows from

$$\overline{i_g} = \frac{W}{\pi R_i}\int_0^{\varphi}(\cos x - \cos\varphi)\,dx = \frac{W}{\pi R_i}(\sin\varphi - \varphi\cos\varphi) \quad (10)$$

We may assume that φ is small, so that we may set:

$$\sin\varphi = \varphi - \frac{\varphi^3}{6},$$

$$\cos\varphi = 1 - \frac{\varphi^2}{2}.$$

Equation (10) thus resolves into:

$$\overline{i_g} = \frac{W}{\pi R_i}\,\frac{\varphi^3}{3} \quad . \; . \; . \; . \; . \; . \; . \quad (11)$$

On the other hand between $\overline{i_g}$, V_g, W and R there exists the relation already used in equation (1)

$$\overline{i_g} = \frac{V_g}{R} \approx \frac{W}{R}, \quad . \; . \; . \; . \; . \; . \quad (12)$$

in which the symbol for "approximately equal to" expresses the fact that V_g and W differ only slightly from each other, which again corresponds to the assumption that φ is a small angle. From (12) and (11) it follows that:

$$\varphi^3 = \frac{3\pi R_i}{R}.$$

With the help of the angle φ thus found we shall now determine the quantity

$$\left(\frac{\delta\,\overline{i_g}}{\delta\,V_g}\right)_{(W\,=\,\text{constant})}$$

occurring in the criterion of stability, equation (9). For that purpose we make use of the relation:

$$\frac{V_g}{W} = \cos\varphi,$$

from which it follows that

$$\frac{\delta\varphi}{\delta V_g} = -\frac{1}{W\sin\varphi} \approx -\frac{1}{W\varphi}.$$

Bij differentiating (11) we now find that

$$\left(\frac{\delta\overline{i_g}}{\delta V_g}\right) = \frac{W}{\pi R_i}\varphi^2\left(\frac{\delta\varphi}{\delta V_g}\right) = -\frac{\varphi}{\pi R_i} = -\sqrt[3]{\frac{3}{\pi^2 R_i{}^2 R}} \quad (13($$

In the cases occurring in practice the grid resistance R is large compared with R_i (for instance $R_i = 1000\Omega$, $R = 50\,000\Omega$). From this it follows that the denominator of the term under the radical is much smaller than R^3, so that $\delta\overline{i_g}/\delta V_g$ is many times as large as $1/R$. We may therefore ignore the first term in the stability condition given by equation (9) and then by substituting (13) in (9) we obtain the stability condition in the form

$$\sqrt[3]{\frac{3}{\pi^2 R_i{}^2 R}} > \frac{1}{2}\,\frac{M}{L}\,\frac{K}{C}\,W\,\frac{\delta S_{\mathrm{eff}}}{\delta W} \quad . \; . \; . \quad (14)$$

From this result the same main conclusions may be drawn as from equation (9). The relation between the stability and, respectively, the internal resistance Ri and the external resistance R between cathode and grid is shown more clearly than in equation (9).

THE INVESTIGATION OF TEXTURE WITH ELECTRON RAYS

by J. F. H. CUSTERS. 539.27 : 620.18.

Due to the strong absorption experienced by electron rays in matter, they are more suitable than X-rays for the investigation of the structure of very thin films. As an example of such an investigation the texture is here discussed of aluminium mirrors which are obtained by depositing the metal by evaporation on a cold glass wall or on one heated to 200° C.

It is now known that in some respects moving particles of matter behave like waves of the wavelength

$$\lambda = \frac{h}{mv} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

(m = mass of the particle, v = its velocity, h = Planck's constant). The first experiments from which this could be directly concluded became known several years after de Broglie had set up equation (1) (1924): by allowing electrons to impinge upon a crystal, diffraction and interference phenomena could be observed quite analogous to those which occur upon the diffraction of X-rays, whilst the phenomena were also quantitatively similar when the wave length given by (1) was assigned to the "material waves".

While in the beginning the phenomena in question were mainly of interest for theoretical physics, they soon proved to be extremely useful as an aid in practical research. In the same way as X-rays, upon diffraction at material particles electron rays are able to give information as to the system, orientation, regularity, etc. of the arrangement of these particles, in other words, like X-rays, electron rays can be used for structural analysis.

In this connection there are two properties of the electron rays which are of special importance: 1) there is a much stronger reaction between the electron rays and matter than between X-ray and matter; 2) the electron rays which can be used practically have a much shorter wavelength than the X-rays suitable for structural analysis.

The first difference involves the fact that with electron rays still smaller and more rarefied quantities of matter are sufficient to cause the diffraction phenomena than is the case with X-rays. Thus electron rays are used preferably to investigate the internal structure of gases or for the structural analysis of organic chemical substances of which sometimes only minimum quantities are available. Furthermore, the intense mutual reaction results in the fact that the electron rays are very strongly absorbed. The penetrating power is a factor of the order of magnitude 10^3 smaller than that of X-rays, and after passing through a layer 1000 Å thick, for example, they are already practically entirely absorbed. This fact makes electrons particularly suitable for the investigation of very thin films, such as metal films deposited in some kind of base. With X-rays in such a case not much can usually be done, since the latter, even when they are given a glancing incidence on the surface to be examined, penetrate too deeply, so that the diffraction pattern of the superficial film is drowned out by that of the more deeply lyings parts.

As to the second point of difference, according to (1) the wavelength of the electron rays depends upon the velocity. If the electron ray consists of electrons which are accelerated by an electrical potential difference V then each electron (charge e) has the kinetic energy

$$\tfrac{1}{2}\, mv^2 = eV \quad . \quad . \quad . \quad . \quad . \quad (2)$$

When the velocity v is eliminated from (1) and (2) and the values of the constants e, m, h are filled in one obtains

$$\lambda_{\text{Å}} = \sqrt{151/V_{\text{volt}}} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If, for example, V = 60 000 volts, λ = 0.05 Å, while the X-rays used for structure analysis have a wavelength of the order of magnitude of 1 Å (for example λ = 1.539 Å for the K_a radiation of copper). The much shorter wave length of the electron rays results in the fact that they are diffracted through much smaller angles than the X-rays. The diffraction of X-rays as well as of electron rays may be considered as a regular reflection at the lattice planes of the crystal lattice of the material investigated, on the understanding that this reflection takes place only when the angle Θ between the incident beam of rays and the lattice plane satisfies Bragg's condition:

$$n\lambda = 2d\sin\Theta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

(d = lattice plane distance, n = a whole number, the "order" of the reflection). With a given set of lattice planes (d) and a given order n of the reflection, the angle Θ also becomes very small with a small value of λ. If for example d = 1 Å and λ has the value already mentioned of 0. 05 Å, the first order reflection (n = 1) occurs

at $\Theta = 1.5°$. In order to obtain diffraction diagrams of reasonable size which can be measured with sufficient accuracy, therefore, the photographic film on which the diffracted rays are allowed to fall must be placed at quite a large distance from the specimen being investigated.

As an example of the application of electron diffraction we shall discuss here the investigation of a l u m i n i u m m i r r o r s which are prepared by depositing the evaporated metal on a glass surface. Such mirrors, which are employed because of their good reflection of infra-red, visible and ultra-violet radiation, are made in the following way. Two tungsten coils are set up in a vacuum opposite the glass wall to be covered. At regular intervals on one coil short pieces of aluminium wire are fastened. When this coil is heated the aluminium evaporates and is deposited on the glass wall in the form of a mirror whose thickness can be regulated simply by the length of time for which the coil is heated. The mechanical properties of the layer of aluminium, especially the h a r d n e s s, are, found to depend very much upon the temperature of the glass surface, which can be varied by heating the second tungsten coil to a higher or lower temperature. While a mirror formed by evaporation onto cold glass (18° C) is soft and unless handled very carefully is easily scratched and marred, uton evaporated onto hot glass, for instance 200° C, hard mirrors are obtained which can be used for technical purposes. A necessary condition is that the glass surface must have previously been carefully cleaned of traces of grease and other contaminations. The effect of heating the glass should also be considered as a cleaning of the surface, because when the heated glass wall is first allowed to cool before the metal is deposited upon it a hard mirror is also obtained.

The obvious question is now whether or not the difference in hardness is correlated with a demonstrable difference in structure of the layers deposited by evaporation. Because of the extreme thinness of the films this investigation can be carried out practically only with electron rays.

By allowing a beam of electrons to fall upon the surface of the mirror at a glancing angle as is sketched in *fig. 1*, the diffraction diagrams reproduced in *figs. 2a* and *b* were obtained in the two cases of evaporation on cold and hot glass respectively. In all respects these diagrams resemble diffraction diagrams obtained with X-rays when there are allowed to fall on a (sufficiently thick) layer of a polycrystalline metal : a number of rings, D e b ij e - S c h e r r e r rings, occur, each of which belongs to a definite set of lattice planes of the crystal lattice of the metal concerned. Such a set of lattice planes will lead to reflection of only those crystals which are so

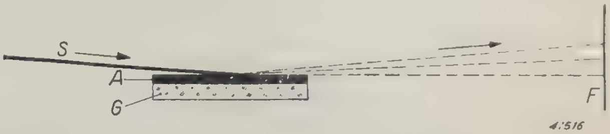
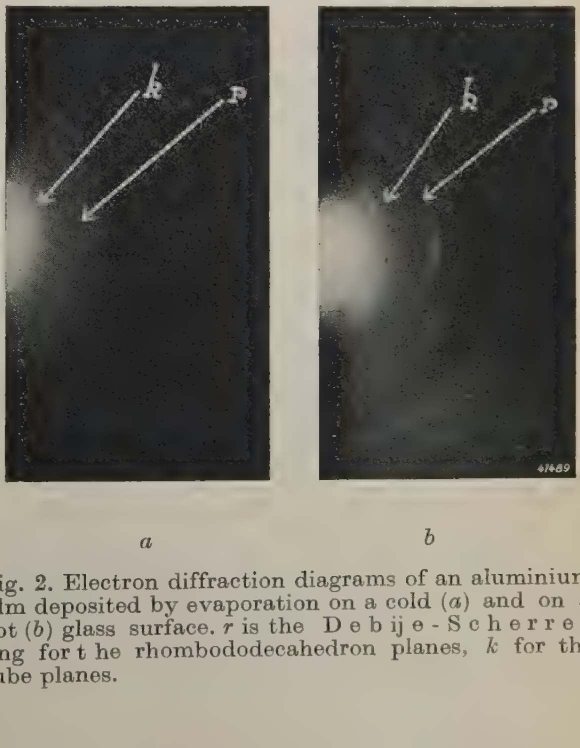


Fig. 1. The electron beam S falls with glancing incidence on the aluminium mirror A deposited on the glass wall G. The rays which are diffracted through very small angles fall on the film F, which is placed at a fairly large distance away (in practice for instance 35 cm).

oriented that the lattice plane makes the angle Θ determined by equation (4) with the electron beam. The rays reflected at this set of lattice planes must therefore always make an angle of $2\,\Theta$ with the direction of the incident beam, *i.e.* they all lie on the surface of a cone around this direction and can only strike the photographic film on the ring where the surface of this cone cuts the film. With glancing incidence of the beam on the specimen being examined there is also the peculiarity that the rays which are reflected toward the i n s i d e of the surface are absorbed in the film, so that in the diffraction diagram only half of the diffraction pattern can be seen: it is as if the rings were half covered by the shadow of the plate-shape specimen.

If the crystals in the polycrystalline metal are entirely at random, the lattice plane being considered will occur in all possible positions, the corresponding ring in this case being uniformly black around its whole circumference. This case is obtained in fig. 2*a*. In fig. 2 *b* on the other hand the rings are not uniformly blackened



a *b*

Fig. 2. Electron diffraction diagrams of an aluminium film deposited by evaporation on a cold (*a*) and on a hot (*b*) glass surface. r is the D e b ij e - S c h e r r e r ring for the rhombododecahedron planes, k for the cube planes.

around the whole circumference, from which it follows that in this case the crystals do not occur in all possible positions, but possess a preference for a certain orientation. The film which has been deposited on hot glass and which is much harder thus possesses a texture.

Several months ago it was explained in this periodical [1]) how such a texture can be further investigated and described by means of a so-called pole figure. In the investigation by means of electron rays this process is often simplified thanks to the fact already mentioned that the angles of reflection Θ are so small, namely of the order of magnitude of 1°. The direction of the electron beam itself, due to the slight divergence always present, cannot be defined more exactly than within about 1°, so that it may be said that the reflecting lattice planes must be practically parallel to the incident beam. Furthermore, as is illustrated by *fig. 3*, every lattice plane is perpendicular to the line joining the centre points of the diagram with the interference spot caused by that lattice plane.

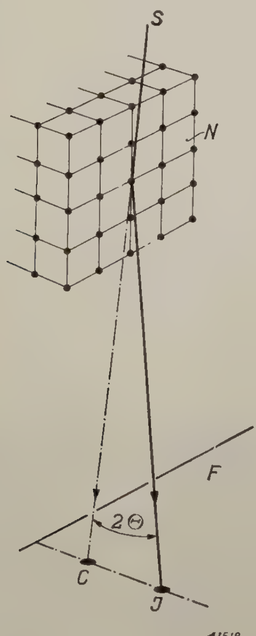


Fig. 3. Reflection of an electron ray at a set of lattice planes. Because of the very small angles of reflection Θ, it may be said that the lattice plane N is practically parallel to the incident beam S. Furthermore the lattice plane is perpendicular to the line joining the spot I which it causes on the film F with the centre interference spot C at which the non-diffracted beam strikes the film.

Let us apply this to the diagram of fig. 2*b* and consider especially the Debije-Scherrer ring (r) which belongs to the rhombododecahedron planes of the cubically crystallizing aluminium. One part in particular of this ring is strongly blackened (white in the reproduction) and the line joining this with the centre is perpendicular to the edge of the shadow of the plate of metal. From this it follows that the *rhombododecahedron planes of the crystals lie preferably parallel to the surface of the mirror.* In *fig. 4* a model is given showing a number of

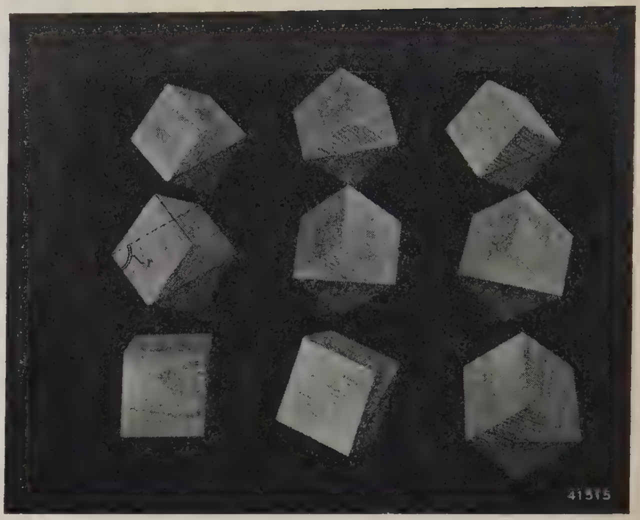


Fig. 4. The aluminium crystals, represented by their elementary cubes, all lie on the glass in such a position that a rhombododecahedron plane r is parallel to the surface.

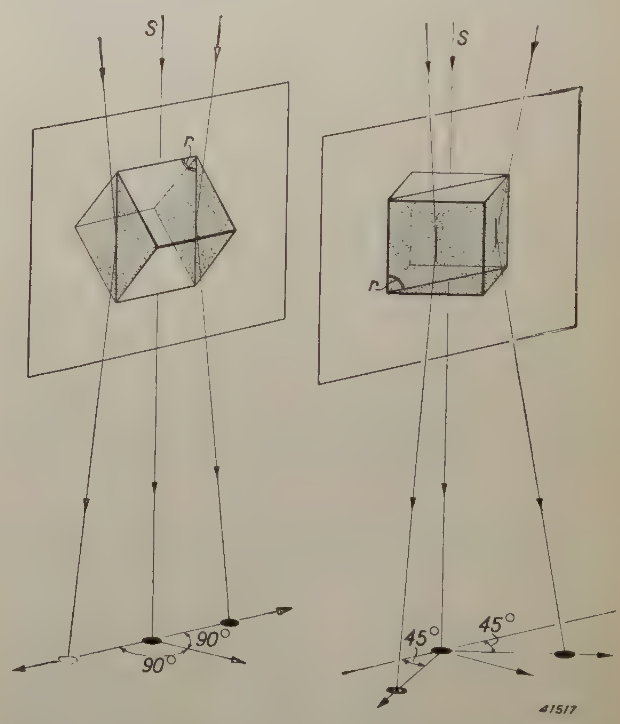


Fig. 5. When a rhombododecahedron plane r is parallel to the surface of the mirror (thus also parallel to the glancing electron beam S), there are only two positions of the crystal in which the cube planes also give rise to reflection. It may be seen that each of two positions produces two interference spots.

1) Philips Techn. Rev. **7**, 13, 1942.

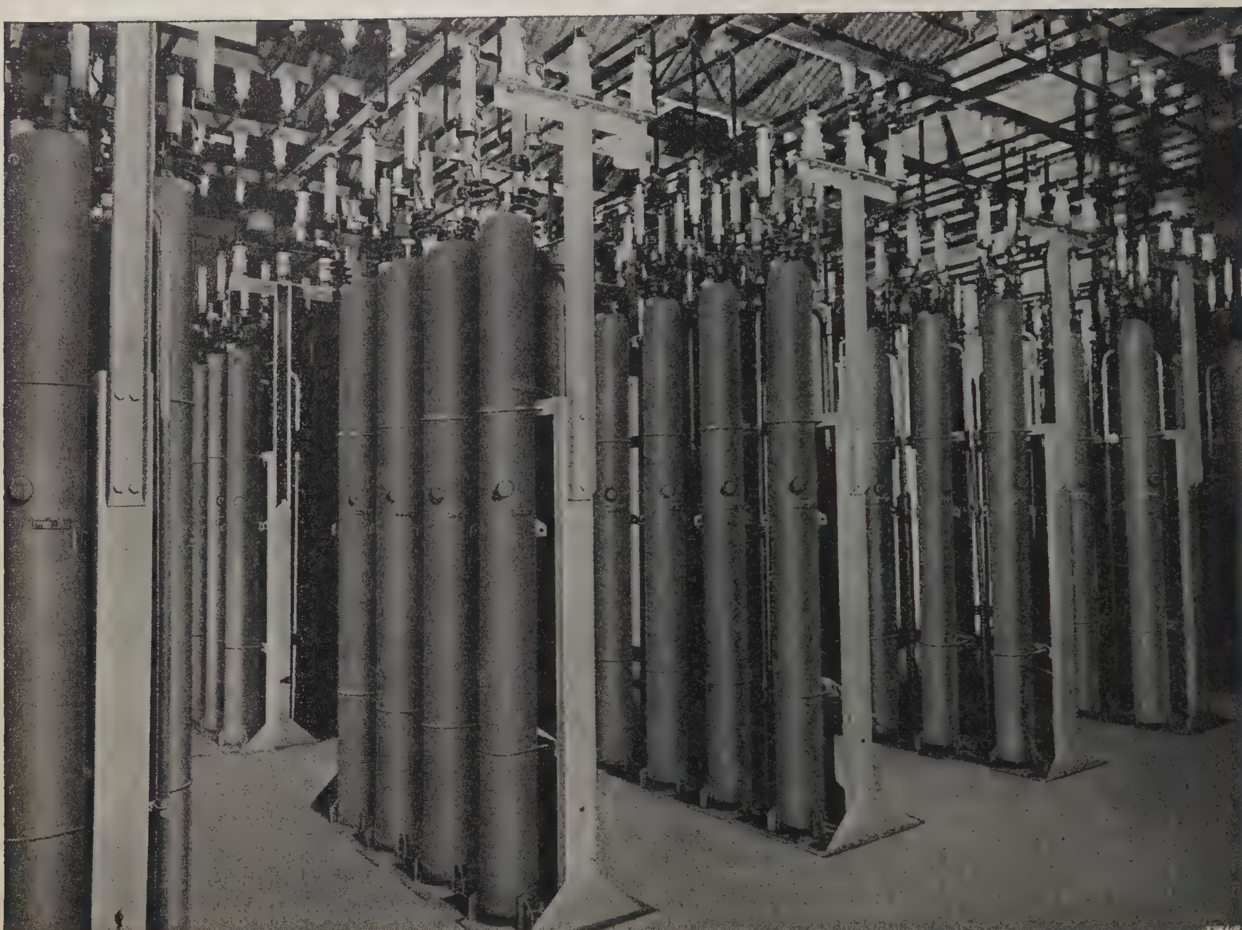
crystals in different positions satisfying this condition.

Now in order to ascertain whether all of these positions actually occur we consider the Debije Scherrer rings of other lattice planes as well, for instance the ring for the cube planes. Out of all the positions of crystals shown in fig. 4 there are only two in which a cube plane lies parallel to the incident beam. These two positions are drawn separately in fig. 5 and at the same time the way in which the reflection will take place is indicated. It is evident that a blackening may be expected on the Debije-Scherrer ring in question at only four points, namely at the intersections with the edge of the shadow and at two points 45° away from that edge. This is actually what is observed in the diffraction diagram. If the mirror is now rotated through any desired angle around the normal to its own surface and a diffraction photograph is again made, exactly the same picture is obtained. From this it follows that then also crystals always occur in the position of fig. 5, in other words all the positions given in fig. 4, in which a rhombododecahedron plane is parallel to the surface of the mirror, actually do occur.

In conclusion it should be mentioned that exactly the same texture as described here is also found in aluminium films deposited by evaporation on molybdenum at 220° C and then heated in a vacuum to 600° C. On the other hand some investigators obtained deviating results in the case of aluminium films on glass, for instance a texture in which a cube edge of the crystals is perpendicular to the surface of the mirror, or where the same is true of a space diagonal of the crystals. Thus in the deposition of the aluminium certain experimental conditions apparently play a part, which conditions must have been different in the different experiments.

A LARGE BATTERY OF CAPACITORS

621.319.4



Battery of capacitors with a reactive power of 10 000 kVA, 6.8 KV/50 c/s, for phase shifting, consisting of 96 Philips pressure capacitors of 105 kVA each.

Attention has already been called in this periodical to the significance of improving the power factor in electric heavy current mains by means of capacitors.

In an AC mains without phase shift the generators at the power station have to supply not only the active power that is transformed in current consumers into mechanical driving power, heat and light, but also the reactive power that maintains the necessary magnetic fields. The production of the active power requires the application of mechanical energy by means of steam engines, water turbines, internal combustion engines. On the other hand, the production of the reactive power does not require the application of any energy and is thus not confined to the location of the power station. It can straightaway be separated from the latter, which may be done by means of capacitors installed in the vicinity of the current-consumer. The reactive current need then no longer follow the long path from the power station over the lines and transformers, which is often more than 100 km (about 65 miles) long. The generators and all the means of transmission lying between the power station and the connecting point of the condensers are relieved of the reactive current. Their capacity increases, and the losses and voltage drops occurring therein are reduced.

Besides the technical advantages with regard to the voltage control, the economic benefits are a saving in expense for the extension of the network of mains on increasing load and a saving in running costs due to lower fuel consumption as a consequence of a reduction in the losses, which may both be very high. At the same time considerable amounts of important raw materials,

[1]) Philips Techn. Review, **1**, 178, 1936.
[2]) Philips Techn. Review, **4**, 254, 1939.

such as copper, aluminium, iron, transformer oil, etc. for enlarging the mains, coal or oil for running, are saved.

Now a few words as to the choice of location for the capacitors. Next to separate installation at the individual works, the concentrated installation of a large condenser capacity at the consumers' end of long transmission lines or at the main point of the reactive load is gradually gaining ground; in this way the power supply company has it in hand to switch capacitors on or off according to the loading conditions.

The above illustration gives an example of capacitors connected at Göteborg (Sweden) to the mains of the Trollhättan power station 140 km (about 90 miles) away. The battery, the reactive power of which is 10 000 kW at 6.8 kV and 50 c/s, comprises 96 Philips pressure capacitors [2]) of 105 RkVA each, which are set up in 12 rows of 8 (diameter 216 mm, height 2735 mm). Each capacitor is protected by high-efficiency fuses. In series with the whole battery are choke coils that consume 4.6% of the mains voltage and detune the frequency of the mains to such a degree that a troublesome amplification of the harmonics of the voltage curve is avoided.

Two further batteries of the same pressure capacitors (5000 RkVA, 6.8 kV each) have been installed at Ornkäldsvik and Brännland on the network of the Norrländska Power Supply Co.

Further to the article mentioned in foodnote 2, we would observe that five years' experience with Philips pressure capacitors for the most varied outputs and voltages is now available and has proved these capacitors to be entirely satisfactory both mechanically and electrically. Almost without exception a refilling of the pressure cylinder with nitrogen was found to be superfluous; in spite of the high field-strength in the dieletric a close inspection did not disclose the slightest traces of ageing phenomena, so that it is perfectly safe to reckon with a practically unlimited life.

THE EQUALIZATION OF TELEPHONE CABLES

by H. van de WEG.

621.392,53

In order to obtain a flat frequency characteristic in a telephone cable a so-called equalization network is connected behind each cable section. In this article the make-up of these networks is discussed and the method is studied which is used to determine the network required for a given behaviour of the cable damping.

When a sinusoidal voltage V_1 is applied to one end of a pair of conductors, a sinusoidal voltage V_2 also occurs at the other end which is in general of smaller amplitude and more or less shifted in phase. This is expressed by writing

$$V_2 = V_1 e^{-g} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and the transmission is in this way characterized by a "transmission factor" g which is in general complex:

$$g = \ln \frac{V_1}{V_2} = a + jb \quad . \quad . \quad . \quad (2)$$

The real part a of the transmission factor indicates the attenuation (damping), the imaginary part b the phase rotation experienced by the sinusoidal voltage upon transmission through the cable. The transmission factor depends not only upon the properties of the cable, but also upon the terminal impedances at the beginning and the end of the cable [1]). More generally, the transmission over any given network terminated in any manner (quadrupole) can also be characterized by such a transmission factor.

In the transmission of speech, music, telegraphy signals, etc. through the cable AC voltages of different frequencies must be transmitted. For each of these frequencies the factor g may have a different value: the cable (with its termination) has a certain "frequency characteristic". For an *undistorted* transmission of all signals this frequency characteristic must now satisfy two requirements: the damping factor a must be independent of the frequency: $a = a_0$, and the phase factor b must increase proportionally with the frequency ω so $b = \omega\tau$. In that case with any given variation with time $F(t)$ of the signal transmitted, the signal received always has the form $e^{-a_0} F(t - \tau)$, *i.e.* the signal received, apart from an attenuation by a factor e^{-a_0} and a retardation by a time τ, is the same as the signal transmitted at every moment.

If we now consider an ordinary telephone cable we find approximately the desired variation with the frequency as far as the phase b is concerned, see *fig. 1*. As to the attenuation a,

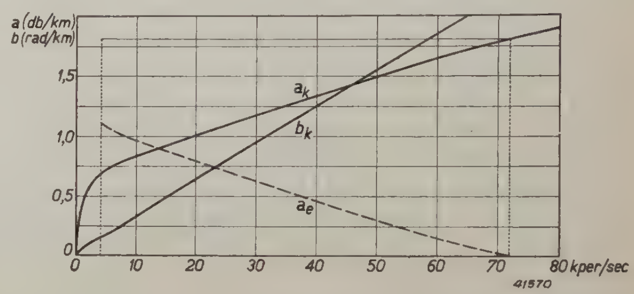


Fig. 1. Attenuation a_k (db/km) and phase rotation b_k (radians/km) of a given cable as a function of the frequency. The broken-line curve indicates the damping a_e which a network should have for the equalization of a section of 1 km of cable in the frequency region from 4 to 72 kc/sec.

however, the requirement of a flat frequency characteristic is by no means satisfied: the damping increases rapidly with the frequency. If the cable is to be used for telephony or telegraphy measures must therefore be taken to make the attenuation independent of the frequency. This can be accomplished by placing between the cable and the receiver a network whose transmission factor g depends upon the frequency in such a way that the cable and network together have exactly the desired frequency characteristic. Since according to the definitions (1) and (2) the damping a of two transmission elements connected one behind the other is at every frequency simply the sum of the dampings of the separate elements, the network to be added must obviously possess the variation in damping indicated in fig. 1 by the broken line. This process, in which the damping of the cable is added to at each frequency to give the same fixed value, is called equalization of the cable and the network in question is called the equalizer.

In most cases no attention need be paid to the phase rotation, since, as mentioned in connection with fig. 1, the deviations of the phase from the desired dependence on the frequency are small ; the distortion thereby caused can only be disturbing in the case of very long

[1]) In this connection one also speaks of transmission factor in use, attenuation in use, etc., when one means the transmission upon termination of the cable by the impedance occurring during normal use. If the cable is terminated at both ends by its characteristic impedance, which case practically is the most favourable and theoretically the simplest to deal with, g, then calculated per km length of the cable, is indicated as the propagation constant $\gamma = \alpha + j\beta$.

cables, for instance for transatlantic communication, or of instance for the transmission of television signals, since the picture is affected by phase rotations to a much larger degree than sound perception [2]). Only in these cases therefore must an "equalization" also be applied for the phase, and certain networks are again used for that purpose.

It may here be noted that equalization is only necessary for the frequency region that is of importance for the signals to be transmitted. For telegraphy, for example, the characteristic need only be made flat to about 75 c/sec.; for the transmission of music to about 10 000 c/sec, etc.

According to the above, equalization always means the artificial increasing of the damping, which from the point of view of economy is undesirable. There is also the possibility of obtaining the desired flat characteristic to a certain extent without extra damping, by changing the cable itself, for instance by coil loading which has previously been discussed in detail in this periodical [3]). In this case the damping in a certain frequency region is not only rendered flat but in addition is considerably lowered. The disadvantage of this method, however, is that in the vicinity of a certain frequency, the limiting frequency, the damping rises so suddenly that the transmission of higher frequencies is quite impossible [4]). In the case of cables for carrier-wave telephony, where a large number of calls are transmitted simultaneously over each pair of conductors by shifting [5]) the speech frequencies to different frequency regions (channels), and where therefore fairly high frequencies must also be transmitted — in a 17-channel system designed by Philips up to 72 000 c/sec, for example —, loading cannot in general be considered. In this case, therefore, in order to obtain an attenuation independent of frequency, recourse must be had entirely to equalization.

It might be asked whet_er in the case of carrier-wave telephony an equalization over the whole frequency region is actually necessary. The requirement of freedom from distortion of the speech to be transmitted, for which a flat frequency characteristic is necessary, is only made of each separate channel, which for instance in the case of the 17-channel system mentioned includes speech frequencies from 300 to 3400 c/sec. If we consider these successive frequency regions (*fig. 2*) the attenuation is found to vary only very little within each channel. When we consider a cable section 30 km long the variations for the highest channels still lie practically within the permissible limit of about 1 db, and for the lowest channels they are not greater than 2.5 db, so that as far as the distortion is concerned an equalization in each channel, which can be realized in a simple way, would be sufficient. The attenuation curve would in this way be supplemented forming a kind of step-like curve. For another reason, however, equalization over the whole frequency region from 4 000 to 72 000 c/sec. is necessary, namely in order to avoid overloading of the line repeaters. These repeaters must be of such dimensions that they provide an amplification which is sufficient to bring the highest channel, which is the weakest at the receiving end, up to the desired level. Since with a cable length of 30 km the lowest channels are already about 30 db stronger than the highest, the repeaters would be very heavily overloaded by the lowest channels. The result of overloading is in the first instance a non-linear distortion in which higher harmonics of each speech frequency as well as combination tones of different frequencies occur which may fall in higher or lower channels and thus cause cross-talk between the various channels. Thus in carrier-wave telephony also an equalization network must be placed behind every cable section in front of the input of the following line repeater (*fig. 3*).

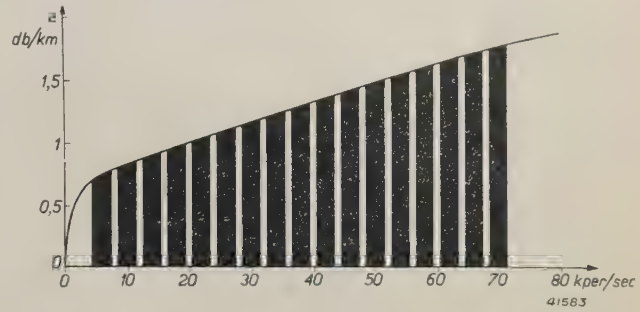


Fig. 2. Cable-damping in the frequency regions of the successive speech channels in a carrier-wave system with 17 channels.

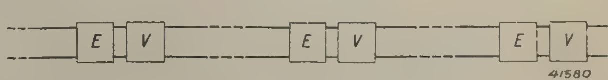


Fig. 3. Cable sections with equalization networks E and line repeaters V.

[2]) On the influence of the phase on the form of a complex vibration and on the sound impression see: J. F. Schouten, Philips Techn. Rev. **4**, 167, 1939.

[3]) See especially: F. de Fremery and G. J Levenbach, Carrier-wave telephony on coil-loaded cables, Philips Techn. Rev. **4**, 20, 1939.

[4]) The damping in the region below the limiting frequency is, moreover, never absolutely constant, so that in addition to loading an equalization must also be applied.

[5]) See: Philips Techn. Rev. **6**, 325, 1941 **7**, 83, 1942; **7**, 104, 1942.

Equalization networks

We shall now examine more closely the networks which can be used for equalization.

Given a cable with a certain damping curve, it is a question of finding a network whose damping factor has a prescribed variation as a function of the frequency, *i. e.* variation which will bring the given damping curve of the cable up to a constant value. Thus formulated generally, and given a certain required precision, the most divergent solution could be proposed for the problem. A restriction is immediately imposed, however, by the requirement that the matching between the cable and the terminating resistance R_0 (*i.e.* the impedance of the final apparatus or the amplifier input, which impedance is made as nearly as possible equal to the so-called wave resistance of the cable) must not be disturbed by the insertion of the equalization network between them. This means that when it is terminated by the ohmic resistance R_0 the equalization network, must also exhibit the resistance R_0 as input impedance. At the same time there is then the advantage that if necessary a second equalization network (satisfying the same conditions) can be placed between the first equalization network and the terminating resistance R_0, and in this way any desired number of equalization networks can be connected one behind the other, each with a different damping curve if necessary, without any change in the transmission properties of each network. Thus it is possible to divide, as it were, the total required damping curve in to different parts and assign each part to a network, which is of great advantage in the case of a fairly complicated shape of the required damping curve.

In *fig. 4* several forms of networks are now given which satisfy the condition mentioned. The impedance indicated by Z_1 may in each case still be composed in any desired way of resistances, self-inductions and capacities. The reciprocal impedance $R^2{}_0/Z_1$ occurring in other branches is then also composed of such elements, and this impedance is found by replacing the elements R_1, C_1, L_1 of the network Z_1 by elements R_2, L_2, C_2 respectively, which satisfy the equations:

$$R_1 R_2 = L_1/C_2 = L_2/C_1 = R^2{}_0,$$

and with which every connection in series in the network Z_1 is replaced by a connection in parallel and *vice versa*. If, for instance, Z_1 is a parallel connection of a capacity C_1 and a resistance R_1, then, as can easily be verified, $R^2{}_0/Z_1$ becomes a connection in series of a self-induction $L_2 = R_0{}^2 C_1$ and a resistance $R_2 = R_0{}^2/R_1$.

The following equation is valid for the damping of a network according to fig. 4*a* :

$$a_{\mathrm{db}} = 20 \log \left| \frac{1 + Z_1/R_0}{1 - Z_1/R_0} \right| \quad . \quad . \quad (3)$$

for the networks according to figs. 4*b*, *c*, *d*:

$$a_{\mathrm{db}} = 20 \log \left| 1 + Z_1/R_0 \right| \quad . \quad . \quad (4)$$

It is clear that by a varied choice of Z_1 a very varied behaviour of a with the frequency can be realized. In *fig. 5* the qualitative behaviour of a is reproduced for the network of fig. 4*b* with several types of impedances Z_1.

The function of an equalization network is to a certain extent analogous to that of a filter. It is therefore perhaps advisable to point out their points of difference. In the case of a filter it is a question of obtaining a damping in a certain frequency region and in another frequency region preferably an entirely unattenuated transmission (zero damping). Therefore for the composition of filters in principle only reactive elements (coils and condensers) are considered which have the lowest possible energy dissipation. "Damping" (without dissipation) is in this case obtained in certain frequency regions only due to the fact that the matching between the filter impedance and the terminating

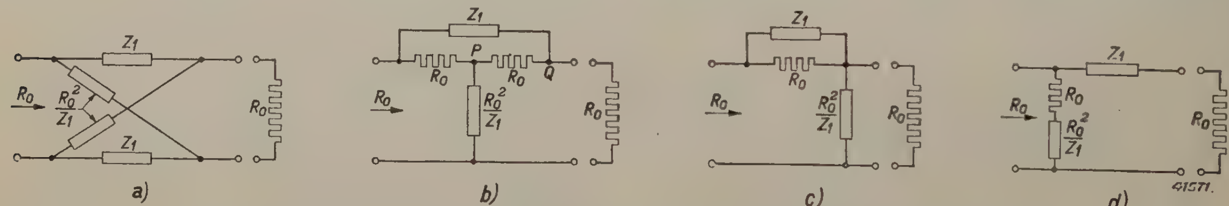


Fig. 4 *a-d*). Four types of equalization networks. All have the property that upon being terminated by a resistance R_0 the input impedance also becomes equal to R_0. With the same value of Z_1 the three types of networks *b*), *c*) and *d*) have the same damping curve (equation 4). This can be explained in the following way: If the network *b*) is terminated by a resistance R_0 it forms a Wheatstone bridge, one diagonal of which lies between the input terminals of the network, the other between points P and Q. It is easily verified that with the impedances indicated the bridge is balanced, so that the resistance R_0 between P and Q carries no current. This resistance can for example: therefore be short-circuited, network *c*) then being obtained. Or the resistance in question may be made infinitely large, network *d*) then being obtained. The transmission is the same in all three cases, provided the left-hand terminals are used as input. If, however, the direction of the transmission is reversed, networks *c*) and *d*) no longer satisfy the initial condition, so that these two networks cannot be used for transmission in both directions.

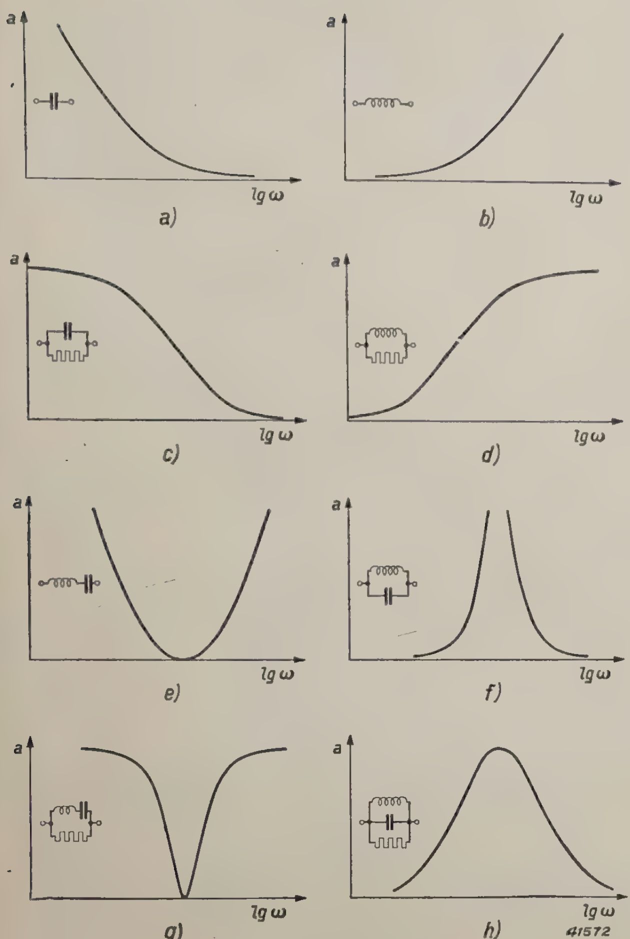


Fig. 5. By building up the impedance Z_1 of the networks in fig. 4 in different ways from coils, condensers and resistances, damping curves of different types can be obtained. For the network of fig. 4b the approximate form of the damping curve is drawn for the most important types of impedance Z_1.

impedance is poor in these frequency regions. Because of this the energy of the incoming signal is partly reflected and does not reach the termination behind the filter. Once the transmission region has been determined, however, the behaviour of the damping of each type of filter in the damping region is entirely fixed, so that owing to the limited number of types of filter there are only limited possibilities of variation. It is clear that by also including resistances in the network much more extensive possibilities are obtained for realizing a given damping behaviour.

It must further be pointed out that equalization is not only used in cables, but that it is sometimes also necessary in the case of other transmission elements (quadrupoles). In the latter case it is sometimes not actually a question of "equalization", but of obtaining a definite (thus not flat) frequency characteristic. Thus, for example, the previously described psophometer characteristic [6]) can also be realized by means of "equalization" networks.

Determination of the network required

How does one now find the impedance Z_1 that has to be taken in the networks of fig. 4 in order to obtain a prescribed form of damping curve? This can be done in different ways. In the first place a certain type of impedance Z_1 may be chosen for the approximate shape of the desired damping curve, and then the necessary equations may be set up for the n elements in this impedance — in the case above these were the two elements C_1 and R_1 — by setting the attenuation a given by (3) or (4) exactly equal to the damping desired at n different frequencies for those frequencies [7]). The calculations are generally quite elaborate and it cannot be seen in advance how much the attenuation for other frequencies will deviate from the desired values. Moreover, it may happen that from the equations values are found for the impedance elements which are not realizable with the available means, for instance negative capacities and the like.

A different method is therefore often preferred, namely the accurate drawing of the damping curves for a large number of networks with different kinds of impedances Z_1, consisting of elements of different values. Given such curves, it is possible by interpolation to find a curve which approaches the desired damping curve as closely as possible. It may seem a hopeless task to draw such curves and to use them, considering the large number of parameters. If, for instance, we take for Z_1 the connection in parallel of C and R already used as an example, the damping curve a (ω) of the equalization network has the three parameters R_0, R and C. Thus for this single type of Z_1 we obtain a threefold family of curves, or $\propto^3$ different curves. Fortunately, however, by a suitable choice of the variables the number of curves to be drawn is found to be very much reduced. If, for example we substitute in equation (4) for a network of the form of fig. 4b the function of Z_1 which corresponds to the connection in parallel of R and C:

$$Z_1 = \frac{1}{\frac{1}{R}+j\omega C},$$

we find for the damping:

$$a = 20 \ \lg \left| 1 + \frac{R/R_0}{1+j\omega RC} \right| . \quad . \quad . \quad . \quad (5)$$

By now choosing the quantity ωRC as independent variable instead of ω we can represent equation (5) as a single family of curves in which only R/R_0 still appears as parameter. In *fig. 6* a number of curves of this family are drawn.

The fact that, with R/R_0 given, the damping a

[6]) Philips Techn. Rev. **7**, 108, 1942.

[7]) O. J. Zobel, Bell System Techn. J. **7**, 438, 1928

depends only on the expression $\omega\ RC$ means that two different prescribed damping curves

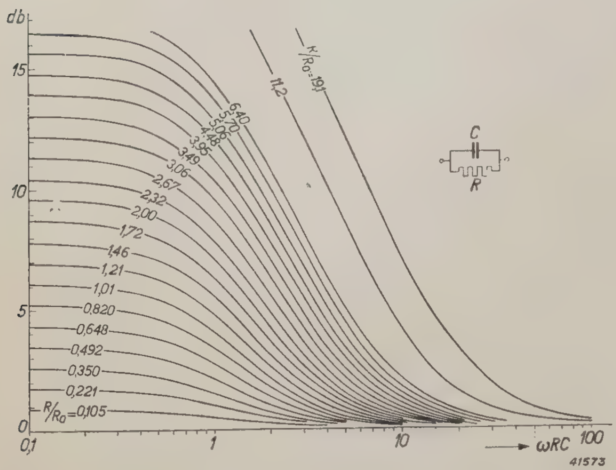


Fig. 6. Damping curves (a as a function of $\omega\ RC$) of networks according to fig. 4*b*, with, a capacity C and a resistance R, connecd in parallel for the impedance Z_1, for a series of different values of the parameter R/R_0. (The same curves indicate the damping for the case where Z_1 consists of a self-induction L and a resistance R; conneted in parallel; the figures along the abscissa then, indicate the quantity $R/\omega L$.)

$a_1(\omega)$ and $a_2(\omega)$ can be realized with the *same* curve $a(\omega RC)$ of our family (thus with the same value of R/R_0), provided a_1 and a_2 satisfy the condition that

$$a_1(\omega) = a_2(k\omega)\ , \qquad (6)$$

where k represents any arbitrary constant. The network securing the damping $a_1(\omega)$ must then be made with $RC = 1$, the network for $a_2(\omega)$ with $RC = k$. With a linear scale for the frequency ω equation (6) means that the curve $a_2(\omega)$ is obtained from the curve $a_1(\omega)$ by expansion or contraction in the direction of the abscissa; with a logarithmic frequency scale on the other hand $a_2(\omega)$ is obtained from $a_1(\omega)$ simply by translation of the curve in the direction of the abscissa, because $\log k\omega = \log\omega + \log k$. For this reason the family of curves in fig. 6 is drawn with a logarithmic abscissa: the prescribed damping curve $a(\omega)$, which has been drawn on transparent paper with the same logarithmic scale for the abscissa, can then simply be laid on fig. 6 and by shifting it in the direction of the abscissa an attempt may be made to make it coincide with one of the curves. If this attempt is successful, the value of the abscissa ωRC can be read off at a definite frequency ω and the required value of RC is then found as the quotient of the two abscissae. An example is given in *fig. 7*, where it may at the same time be seen that in order to make two curves coincide a mutual shift of the two graphs in the direction of the ordinate may also be used. Such a shift means only an increase in the damping by an

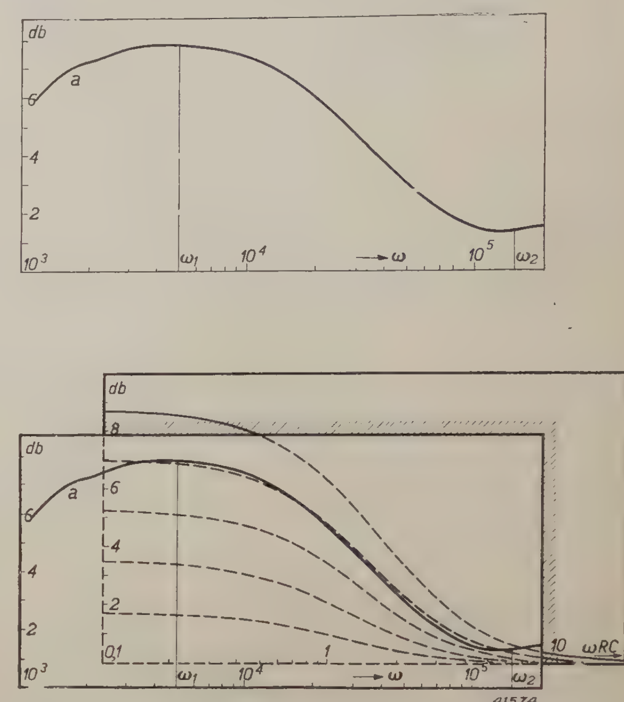


Fig. 7. Example of the manipulation of the families of curves. a is the prescribed damping curve which must be realized as well as possible in the frequency region indicated from ω_1 to ω_2. The curve a drawn on transparent paper is laid on the family of curves of fig.6 and by moving it about it can be made to coincide approximately with the curve for which $R/R_0 = 1.21$. With this position of the two pieces of paper the abcissa ω_1 lies at $\omega RC = 0.22$, the abscissa ω_2 at $\omega RC = 6.6$. From this it follows that $RC = 0.22/\omega_1$ or $6.6/\omega_2$, which must of course give the same result.

amount which is the same for all frequencies, and is therefore - although not desirable in practice — permissible for the equalization.

Fig. 8 gives the family of curves for an equalization network according to fig. 4*b* with a different impedance Z_1, namely a connection in parallel of a resistance R with a self-induction L and a capacity C in series. In this case the four parameters R, L, C, R_0 can be reduced to two, *viz.* $\sqrt{L/C}/R_0$ and R/R_0, when $\omega\sqrt{LC}$ is plotted as abscissa. A twofold family of curves is thus retained. Here also by the use of a logarithmic abscissa scale an attempt may be made to make a given damping curve coincide with one of the curves simply by shifting.

The construction of the family of curves need only be done once, and the number of curves whose shape must be calculated is very much reduced in the manner described. Nevertheless, the preparation of the graphs always requires extensive calculations. This can be entirely avoided by a simple method of

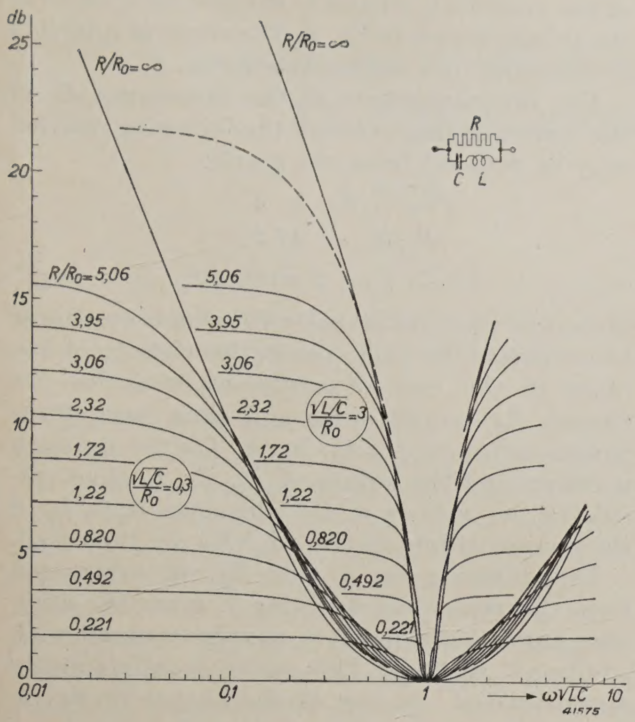


Fig. 8. Damping curves (a as a function of $\omega\sqrt{LC}$) of networks according to fig. 4b with, for the impedance Z_1, a resistance R in parallel with a self-induction L in series with a capacity C. In this case a family of curves is obtained, each family being characterized by a certain value of the parameter $\sqrt{L/C}/R_0$ and each curve by a certain value of the parameter R/R_0.

m e a s u r i n g. The arrangement sketched in *fig.* 9 is used. Between the output voltage V_2, which can be measured with the voltmeter V, and the input voltage E, which is furnished by a tone generator, there is the following relation:

$$V_2 = \frac{E \cdot R_0/2}{R_0 + Z_1}.$$

Furthermore the voltage V_1 is always equal to E_2, since the adjustable attenuator T has at all positions an input resistance R_0. For the ratio V_1/V_2 the following thus holds:

$$\left|\frac{V_1}{V_2}\right| = \left|\frac{R_0 + Z_1}{R_0}\right| = \left|1 + \frac{Z_1}{R_0}\right|.$$

If now for every frequency of the tone generator the attenuator is so adjusted that $V_2 = V_2'$, which is checked by comparing the voltmeter indications at the two positions of the switch S, and if the attenuator is calibrated in db, the position the attenuator immediately gives the quantity

$$20 \log \left| 1 + \frac{Z_1}{R_0} \right|.$$

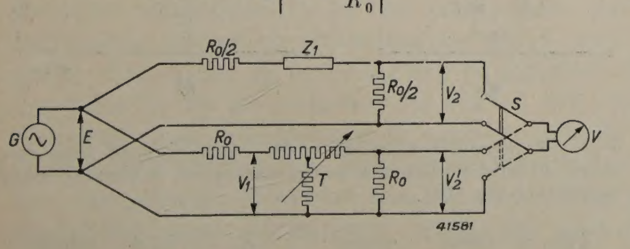


Fig. 9. Connections for recording the damping curves of equalization networks according to fig. 4b. G tone generator, T variable attenuator calibrated in db, S switch, V voltmeter.

According to equation (4) this is exactly the expression for the damping of a network according to figs. 4 b, c, d with the impedance in question Z_1. The variation of damping with the frequency can in this way be very rapidly and easily determined for every set of values of the parameters of Z_1.

Actually the method foils down to the same thing as if the damping of the network of fig. 4b were measured directly. Since, however, in this measurement the condition concerning the terminating impedances does not need to be satified, the network could be replaced by the simpler one shown in the upper half of fig. 9. The advantage in this case is that for each set of parameters it is not also necessary to realize the reciprocal network, which is particularly convenient when one can be saved the trouble of regulating coils, which is always much more difficult than setting condensers.

We shall now explain in more detail the practical process of equalization on the basis of an example.

Practical process of equalization

First of all in a practical case it has to be determined what damping curve the equalization network must possess. The data required can most easily be obtained by m e a s u r i n g the damping of the section of cable to be equalized as a function of the frequency. If this is impossible, as for instance in the case of installations which have to be fuelly worked ont in advance, the damping curve must be c a l c u l a t e d. When doing so account must be taken of the fact that the amplifiers, transformers etc. may also all have a definite frequency characteristic which is not flat. All these characteristics should be combined. Furthermore, the termination of the cable plays an important part. If the cable is terminated by its characteristic impedance, only travelling waves occur in the cable and its damping curve can be derived in a simple way from the cable characteristics (L, C, R and G per km). Usually, however, the impedance of the termination of the cable will not be exactly equal to the lowest frequencies. The energy arriving at the ends is then partially reflected, the degree of reflection (*i.e* the magnitude of the energy loss) depending upon the frequency. In the case of not too long cables the situation becomes even more complicated, due to the fact that the energy reflected at the end of the cable is partly reflected again and then once more furnishes an appreciable contribution at the end, which this may even be repeated several times. Formulae have been developed for making extact allowances for all these corrections to the variation of the damping of any given quadrupole as a function of the frequency. We shall not go into them here, however, and shall assume that the damping curve to be equalized is already given, either by calculation or by measurement.

Let us now suppose that curve *1* in *fig. 10* is the desired variation of the damping of the equalizer. It is here a question of equalizing a carrier-wave cable for the frequency region from 4 to 72 kc/sec with a tolerance of ± 1 db. Upon

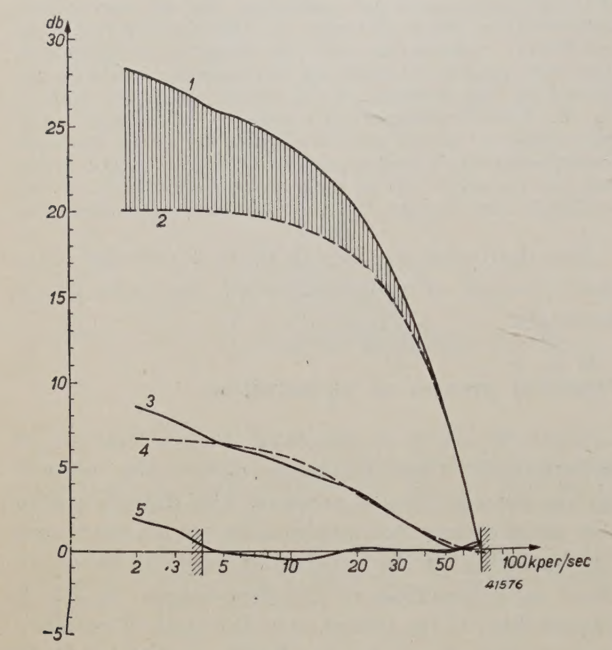


Fig. 10. Example of the manner in which equalization is accomplished. Curve *1* is the desired damping curve; curve *2* is furnished by a first equalization section (fig. 11*a*). The difference (curve *3*) is approximated by the damping curve *4* of a second equalization section (fig. 11*b*). The discrepancies finally remaining are shown in curve *5*: at all frequencies within the frequency band to be used they are smaller than 0.5 db.

comparison of this curve with the curves of the different graphs it is evident that the desired shape cannot be realized with a single equalization network of the types considered. A damping curve must therefore first be separated which can be obtained with the first equalization section, and then the rest of the damping must be contributed by a second or if necessary several more sections. This separating can be done more or less arbitrarily. For curves with the approximate shape of fig. 10 — a rapid drop in the damping towards high frequencies — it will always be necessary, however, for practical reasons to begin by matching the the damping to the requirement at the h i g h est frequencies. Furthermore, the damping for the first equalization network to be chosen should lie preferably entirely b e l o w the desired curve, since otherwise, in order to avoid having to provide negative dampings in the following sections, a constant damping would have to be added over the whole frequency region. In this way we arrive at the choice of curve *2* in fig. 10, which, apart from a constant damping difference for all frequencies (displacement in the direction of the ordinate), is exactly realized by a curve of the family drawn in fig. 8. The curve in question is indicated by a dotted line in fig. 8.

For the parameters of the impedance Z_1 of the corresponding network the following relation may be read off from the graph:

$$\sqrt{L_1/C_1}/R_0 = 3,$$
$$R_1/R_0 = 11.2,$$
$$1/\sqrt{L_1 C_1} = 2\,\pi \cdot 80\,000.$$

Since the wave resistance with which we choose to terminate the cable lies in the vicinity of 150 ohms in the case of carrier-wave cables, we choose $R_0 = 150$ ohms and then have three equations for R_1, C_1, L_1. In *fig. 11a* the network is drawn and the values of R_1, C_1, L_1 thus calculated, as well as of the elements R_2, C_2, L_2 of the reciprocal impedance (R_0^2/Z_1) are indicated.

The damping curve *2* in fig. 10 subtracted from the prescribed damping *1*, gives the damping curve *3* which must now be realized with additional sections. This curve is satisfactorily approximated by one of the curves of fig. 6, namely the curve with parameters

$$R/R_0 = 1.458,$$
$$1/RC = 2\,\pi \cdot 15\,000.$$

R_0 must of course again be chosen equal to 150 ohms. In this way one obtains the second section shown in fig. 11*b* with the values there indicated for the elements R_3, and C_3 of the impedance Z_1, and R_4, L_4 of the reciprocal impedance R_0^2/Z_1. The damping curve of this equalization network, again except for a constant damping difference, is given by curve *4* in fig. 10. The difference between this curve and curve *3*, which finally gives the remaining errors in the equalization, is plotted as curve *5*. It may be seen that the deviations in the whole frequency region from 4 to 72 kc/sec amount to a maximum of ± 0.5 db.

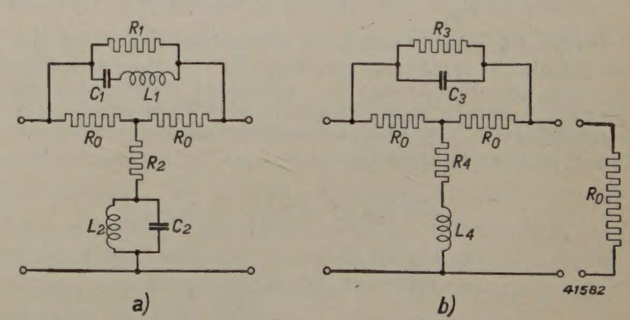


Fig. 11. Equalization network consisting of two sections *a*) and *b*) for the equalization of a carrier-wave cable (see fig. 10).

$$a)\begin{cases} R_1 = 1680 \text{ ohms} \\ C_1 = 0.00442\ \mu\text{F} \\ L_1 = 895\ \mu\text{H} \end{cases} \qquad \begin{matrix} R_2 = 13.4 \text{ ohms} \\ L_2 = 99.5\ \mu\text{H} \\ C_2 = 0.0398\ \mu\text{F} \end{matrix}$$

$$b)\begin{cases} R_3 = 219 \text{ ohms} \\ C_3 = 0.0484\ \mu\text{F} \end{cases} \qquad \begin{matrix} R_4 = 103 \text{ ohms} \\ L_4 = 1090\ \mu\text{H} \end{matrix}$$

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF N.V. PHILIPS GLOEILAMPENFABRIEKEN N.V.

1575: M. J. Druyvesteyn: An approximate calculation of the thermal expansion of solids II (Physica **8**, 862 — 867, September 1941).

The elasticity theory of an isotropic is extended by taking into account the anharmonic terms of the mutual elastic coupling of the particles of the material. Terms which would give rise to anisotropic properties are ignored. An equation is found for a relation between the constant γ of Grüneisen and the lateral contraction . For most metals crystallising with cubic symmetry the results agree very well with the experimental findings, but in the case of alkali metals there are large deviations.

1576: A. Claassen and J. Visser: Die Trennung und Bestimmung von Titan und Aluminium mit Ortho- Oxychinolin (Rec. Trav. chim. Pays Bas **60**, 715 - 727, September - October 1941). The separation and determination of titanium and aluminium with ortho-oxychinnoline.

Berg's method for determining titanium with ortho-oxychinnoline yields doubtful results owing to the incomplete precipitation of the titanium. The titanium can be completely precipitated when the reaction takes place in a tartaric acid solution in the presence of an excess of ammonium sulphate and this solution after boiling is left on the water bath for one to two hours. A further condition is that the hydrogen ions must have a concentration of at most $10^{-5.2}$ grams equivalent ($P_H = 5.2$). If a citric acid solution is used no ammonium sulphate need be added. Quantities of tartaric acid or citric acid larger than 1 gram increase the solubility of the precipitate. Specifications are given according to which quantities of titanium up to 40 mg can be determined analytically to an accuracy of 0.1 — 0.2 mg. Gravimetrical determinations always yield too high results owing to the difficulty in washing out the precipitate. Titanium can be very sharply separated from aluminium with the aid of ortho-oxychinnoline in oxalic acid solution provided the hydrogen ion concentration lies between $P_H = 5.6$ and 6.5. Separation in malonic acid solutions yields inaccurate results.

1577: J. van Slooten: The transformer properties of a four-polar system. (T. Ned. Radio-Genootsch. **8**, 217-234, November 1941).

An electric four-polar system can be regarded as a transformer converting an impedance between the output terminals into another impedance between the input terminals. The latter is conceived to be a function of the former. It is known that generally speaking two output impedances (so-called iterative impedances) can be indicated and in this transformation they do not change in value. With the aid of this property the four-pole equations can be cast in a form which offers advantages for various applications. In this article two simple diagrams are given for cases where the four-polar system consists of a non-ideal transformer (with finite self-inductances and spread) or of a piece of no-loss cable.

1578: E. J. W. Verwey and P. W. Haayman: Electronic conductivity and transition point of magnetite ("Fe_3O_4") (Physica **8**, 979-987, November 1941).

Experiments with some sintered rods of magnetite (Fe_3O_4) have shown that when passing a conversion temperature in the neighbourhood of 120°K the electrical resistance changes by leaps and bounds. When cooling the resistance increases by a factor of 100. This article shows that this phenomenon depends to a large degree upon the stoichiometrical composition of the homogeneous spinel phase, which can be expressed by the ratio of iron to oxygen or by that of ferro-oxide to ferri-oxide. With a small excess of oxygen the above mentioned sudden increase in the resistance is gradually reduced and the conversion temperature lowered several tens of degrees until ultimately the phenomena of conversion entirely disappear. These phenomena are believed to be related to a theory previously put forward in connection with the crystal structure of magnetite (in particular the distribution of the bivalent and trivalent ferro ions in the lattice) and the related mechanism of electro-conductance.

1579: M. J. Druyvesteyn and J. L. Meyering: Elastic constants in the system Cu-Zn (Phy sica **8**, 1059-1074, November 9141)

A method is described for determining the elasticity and torsion moduli of rods from their longitudinal vibrations (*cf*. Philips Techn. Rev. **6**, 372, 1941). The elasticity and torsion moduli are measured for poly-crystalline material in the system Cu-Zn, from which the characteristic temperature is then calculated. It appears that in the system mentioned these moduli have a minimum value (for β brass) and a maximum value (for γ brass).

1580: E. J. W. Verwey: The charge distribution in the water molecule and the calculation of the intermolecular forces (Rec. Trav. chim. Pays Bas **60**, 887-896, November 1941).

From calculations of the electrical alternating potential between monovalent ions and water molecules in aqueous solutions it has been found that the model according to Bernal and Fowler (and also similar models) is inadequate for the charge distribution in the water molecule. A model is therefore proposed which in essential points means an improvement upon that of Bernal and Fowler. The centre of the negative charge of the molecule is then only a small distance away from the oxygen nucleus. The model supplies the sublimation heat of ice with sufficient accuracy. In particular the influence is investigated of various hypotheses concerning the degree of screening of the proton charges in the molecule.